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BELOVED
PARENTS

STUDIES ON PRODUCTIVITY OF *Albizia amara* (ROXB.) BOIV. BASED SILVOPASTORAL SYSTEMS IN BUNDELKHAND REGION

THESIS
Submitted to the Faculty of Science
Bundelkhand University, Jhansi

For the Degree of
Doctor of Philosophy
in
Botany

By
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JHANSI-284 003
2000

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CERTIFICATE

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The candidate had worked under my guidance and supervision for the period required under the University's Research Ordinance -7. The candidate has put more than required attendance at this institute during this period.

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ACKNOWLEDGEMENT

I deem it to be a great pleasure to express my esteemed gratitude to Dr. M. M. Roy, Sr. Scientist, Division of Grassland and Silvopasture Management, Indian Grassland and Fodder Research Institute, Jhansi for his valuable advice, inestimable help and inspiring guidance throughout the course of investigation and preparation of thesis.

I express my deep sense of gratitude to Director, Indian Grassland and Fodder Research Institute, Jhansi for providing necessary facilities during the tenure of my course.

I greatfully acknowledge to Dr. Vinod Shankar, Principal Scientist and Head, Division of Grassland and Silvopasture Management, Dr. B. K. Trivedi, Sr. Scientist (Eco. Botany), Dr. J. N. Gupta, Sr. Scientist (Eco. Botany) and Dr. J. P. Singh, Scientist Sr. Scale (Eco. Botany) for their help in identification of plant species and valuable suggestions during the course of investigation.

My sincere thanks are due to Dr. R. C. Singh, Sr. Scientist (Agron.), Dr. S. S. Parihar, Sr. Scientist (Eco. Botany), Dr. S. K. Gupta, Scientist Sr. Scale (Eco. Botany), Dr. S. K. Sharma, Scientist Sr. Scale (Hort.), Mr. T. A. Khan, Scientist Sr. Scale (Statistics), Mr. M. P. Rai, Expt. Scientist, Mr. B. K. Chaubey, Expt. Scientist, Dr. S. K. Soam, Scientist (Eco. Botany), Dr. J. P. Singh, Scientist (Geog.), Dr. Sudhir Kumar, Scientist (Hort.), Dr. Sunil Kumar, Scientist (Hort.), Mr. Deepanker Saha, Scientist (Eco. Botany) and Dr. G. Suresh, Scientist (Agron.) for their constant encouragement and inspiration.

I am also greatful to Sh. N. C. Srivas, Sr. Technical Officer, Dr. D. K. Singh, Tech. Assistant, Sh. Pooran Singh, Tech. Assistant, Sh. Rajendra Singh, Tech. Assistant, Sh. Shyam Lal, Lab. Attendant and Sh. Khoobi Ram, Lab. Attendant for their help in chemical analytical work in this investigation. Help rendered by Dr. R. B. Yadava, Scientist Sr. Scale (Soil Science) in soil analytical work and Mr. Pradeep

Bihari, Scientist Sr. Scale (Physics) for providing meteorological data throughout the investigation are also acknowledged.

My sincere thanks are due to Sh. Tirath Raj Maurya, Sr. Tech. Assistant and Sh. Ballo Verma, Supporting Grade for their help in field experiment and data collection during the course of investigation. Assistance provide by Mr. M. C. Jetwani, (Jr. Clerk) and Mr. N. K. Tripathi, (Cartographer) are also acknowledged.

I am specially thankful to Mr. M. M. Rastogi, Sr. Technical Officer (Library), Mrs. Seema Khatri, Sr. Tech. Assistant, Mr. V. K. Paliwal, Sr. Clerk and Mr. Mathura Singh for providing help in all kind of library facilities.

The help encouragement and moral support by my father Sh. Prem Narayan, mother Smt. Shanti Devi, buaji Smt. Shanti Bai, elder brother Mr. Jitendra Kumar, bhabhi Smt. Sanjeevani and younger brother Shailendra Kumar can't be expressd in words. I can't express my feeling towards my family members and friends for all round support, persistant encouragement and providing all round lofty idols in my life.

Finally, the financial support providing by Indian Council of Agricultural Research, New Delhi is also acknowledged.

Date: 02.3.2000

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ACRONYMS/ABBREVIATIONS

A. D.	*Anno Domini*
ADF	Acid Detergent Fibre
AG	Aboveground
BG	Belowground
°C	Degree Celsius
Ca	Calcium
CAZRI	Central Arid Zone Research Institute
cd	Collor diameter
cm	Centimeter
CP	Crude Protein
Cv	Cultivar
dbh	Diameter at breast height
DM t/ha	Dry matter tonnes per hectare
FAO	Food and Agriculture Organisation
g	Gram
ha	Hectare
IGFRI	Indian Grassland and Fodder Research Institutre
K	Potassium
km	Kilometer
m	Meter
MAI	Mean annual increment
mm	Millimeter
MPTS	Multipurpose Trees and Shrubs
MS	Microsite
N	Nitrogen
NDF	Neutral Detergent Fibre
OC	Organic carbon
P	Phosphorus
PAR	Photosynthetically active radiation
pH	Potentiality of hydrogen ions
RH	Relative Humidity
t	Tonnes
t/ha/yr	Tonnes per hectare per year

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CHAPTER 1 INTRODUCTION

Land degradation is one of the greatest challenge facing mankind. According to an estimate as much as 2 billion ha of land that were once biologically productive are now degraded. The current rate of land degradation is estimated at 5-7 million ha/year and this rate may increase to 10 million ha/year by the turn of this century (Lal and Stewart, 1990).

In India, 175 million ha of the total geographical area is degraded in one or the other way and about 6600 million tonnes of soils are displaced and carried to ocean annually (Singh *et al.*, 1994). The operating factors for land degradation include sheet erosion, water logging, salinity and alkalinity, wind erosion, stream erosion, shifting cultivation and sand dunes etc. Out of 90 million ha of uncultivated degraded lands, 35 million ha are with forest department, 20 million ha with government/community are used for grazing and the rest of 35 million ha are either owned by individuals or encroached by them (NWDB, 1986; Sehgal and Abrol, 1992; Singh and Chauhan, 1994). Similarly, in Bundelkhand, out of 7.16 million ha reporting area, about 5.02 million ha or nearly 70 per cent area suffers from varying degrees of degradation (Nitant and Tiwari, 1991).

Deforestation is identified as one of the major cause of land degradation in tropical countries, including India. The causes of degradation include population increase, transfer of forests land to agricultural uses, per capita rise in consumption of wood etc. Out of 329 million ha geographical area, India has about 75.35 million ha forest cover constituting 23.4 per cent of the total geographical area. However, recent analysis of satellite imageries have shown that only 38.56 million ha has effective crown density (> 40 %). 25.08 million ha of forest area has low crown density ranging from 10-40 per cent. The remaining forest land (< 10 % crown cover) is fully degraded (Tewari, 1994 b). The existing area under forest cover is also facing severe deforestation at the rate of 1.3 million

ha per year. This situation has also resulted in soil erosion, ground water depletion, frequent floods and droughts (NRSA, 1982).

In India, increased land degradation is primarily due to increase in human and livestock population, which is at present 0.89 and 0.48 billion and is likely to exceed 1 billion and 0.6 billion, respectively by the end of the century. India with only 2 per cent of the world's geographical area has to provide various needs of its ever increasing human and livestock population which is about 16 and 20 per cent, respectively of the world (Deb Roy, 1992). The Bundelkhand region supports a population of 12.45 million human and 9.43 million livestock. This population is increasing continuously. On account of this there has been a decline in the productivity and availability of grazing lands (Tyagi, 1997).

The problem of over grazing is faced all over India, because of huge livestock population and lack of specially identified and regularly managed pastures. The grazing pressure is over 3.3 Adult Cattle Unit (ACU)/ha against the carrying capacity of less than 1 ACU/ha (Dabadghao and Shankarnarayan, 1973; UNESCO, 1979). According to Chakravarty (1971) an area of over 1 million ha in the arid and semi-arid regions is subjected to grazing by 7.4 million cattle, 5.6 million sheep, 3.3 million goats and 0.5 million livestock of other kind against the carrying capacity of 2.5 sheep/ha or 1 cow/2.4-4.0 ha.

The grazing pressure on the rangelands of Bundelkhand region is still higher, nearly 5 ACU/ha. It is higher than the national (2.5 ACU/ha) and the state (0.67 ACU/ha) average (Singh and Singh, 1994). The carrying capacity of a well managed rangeland in the region does not exceed 1 ACU/ha (Shanker *et al.*, 1988). The increased grazing pressure leads to the removal of perennial grass cover and succession of weeds and annuals, this situation accelerates erosion process that accentuates soil fertility.

The grazing demands for maintaining higher animal productivity and economic returns from the animal is estimated to the order of 1253 million tonnes dry matter per year by the end of this century. This requirement when split into dry and green works out to be 949 and 1136 million tonnes, respectively. As

against these, the present availability is 199, 215, 13 and 11 million tonnes of dry fodder, cultivated green fodder, natural herbage and concentrate which could be raised upto 357, 695 and 78 million tonnes, of dry, green fodder and concentrate, respectively by 2000 A.D. (NWDB, 1990).

In Bundelkhand region, the demand of fodder is 11.87 million tonnes against the supply level of 8.48 million tonnes, thus region has a deficit of over 3.0 million tonnes of fodder (Tyagi, 1997). This huge gap in availability and requirement of fodder has resulted in unlimited and unrestricted grazing in forest lands. More over in India, we do not have natural grassland in true ecological sense. Grass here is either a seral or a retrogression stage. This ecological status and huge cattle population are disproportionate to the bearing capacity which leads to the formation of degraded lands (Lal, 1990; Maithani, 1990).

The energy crisis is likely to assume an alarming situation in the country and firewood plantations are required on degraded land. Firewood still constitutes the primary source of cooking for nearly 70 per cent of the population in the country. The firewood is progressively collected from dead wood to the lopping of live trees and from felling of trees to eventually uprooting of stumps and removal of shrubs. The firewood consumption in the country is to the tune of 235 million cubic meter while the sustainable level of production is only 40 million cubic meter. By 2000 A.D., the firewood demand is likely to be 385 million cubic meter for which about 40 million ha additional land area would be needed (Lal, 1990).

Similarly, Bundelkhand region also suffers acute firewood scarcity. Availability from all sources was estimated to be 0.06 million tonnes while the requirement of this region is 2.5 million tonnes (Singh and Singh, 1994). The shortage of firewood and the resultant high price leads to the practice of burning agricultural residue and animal dung. Annually 80-100 million tonnes of dried dung cakes, which represent 400-500 million tonnes of freshly collected dung are burnt. This practice deprives the cultivated land of the much needed precious

organic manure for increasing crop and other biomass production (Deb Roy, 1994).

In addition, the current requirement of timber is around 30 million cubic meter which is likely to be 65 million cubic meter by the end of this century, while current permissible limit is only about 12 million cubic meter. In Bundelkhand, projected demand of timber is 0.26 million cubic meter against the supply level of 0.09 million cubic meter (Lal, 1990; Singh and Singh, 1994). This gap in some places, has built up enormous pressure on the adjoining forests. This alarming situation emphasizes the need for massive afforestation programmes on degraded lands and other problem sites (NWDB, 1986).

In order to meet the increasing demand of forage and fodder for our huge livestock and wildlife on the one hand and firewood and small timber for our daily needs besides to meet the national target of 33.3 per cent area under tree cover on the other hand, there is no alternative but to adopt an integrated approach of growing fodder cum firewood yielding trees along with grass/grass-legume mixture on degraded lands under integrated silvopastoral system (Sahoo, 1996).

Such a concept of developing silvopastures is not new in forestry. It is, in fact, based on sound ecological principles and is very near to natural approach, providing rural needs on one hand and environmental conservation on the other hand, especially in arid/semi-arid region (Pathak and Roy, 1994).

Such systems assist the process of rehabilitation and ensure maximum resource conservation. Major soil nutrients get enriched under silvopastoral system when compared to intensively cultivated systems. Thus such system promise healthy environment and rich biodiversity, which is an important support system on the earth (Pathak and Roy, 1994).

These man made silvopastoral agroecosystems, like the natural forest ecosystems are comprised of a set of interacting biological and physical components. In this type of agroecosystem, growth and architecture of tree component is of paramount improtance. This may ensure appropriate canopy for light penetration to the ground level (Ramakrishnan, 1987). Improved biomass

production per unit area may be achieved because of deep rooting behaviour of trees which can absorb water and nutrients from deeper layers. The trees also ameliorate the soil. Thus, conditions as falling litter add organic matter and nutrients to the systems.

In silvopastoral systems, microclimate amelioration involving favourable soil moisture and temperature regimes may be beneficial for crop and livestock (Willey, 1975; Rosenberg *et al.*, 1983). Also it has been shown that shade and high quality fodder are important requirements for better productivity and higher reproduction of livestock in the tropics, therefore, the judicious inclusion of trees into crop and pasture lands may yield desired benefits (Ani *et al.*, 1985).

Some preliminary information is available, in pieces, regarding growth and bioproductivity of these systems. However, there is lack of information on growth, productivity, microclimate and nutrient cycling aspects of these systems in a holistic frame work. With the growing emphasis of promoting these systems on a larger scale, it becomes extremely important to understand and analyze such systems in an ecosystem context.

It is, therefore, relevant to find out how and why these system functions? Such a piece of information may be used to improve these systems and also to design other systems which can survive and continue to be useful under changing environmental and social conditions (Ong, 1991).

The proposed study envisages to analyze productivity of *Albizia amara*; an important indigenous, multipurpose and nitrogen fixing tree; having very high potential for afforestation on degraded lands, especially the Bundelkhand tract.

In order to achieve the objectives, studies on some aspects of productivity and nutrient turnover of *Albizia amara* based silvopastoral systems *viz.*, (i) growth and productivity of tree component; (ii) growth and productivity of pasture component (iii) microclimate (iv) seasonal litter fall pattern (v) litter decomposition pattern (vi) nutrient accumulation in different plant part of tree and pasture components (vii) soil fertility changes were undertaken during 1997-1998 at IGFRI, Jhansi. The results are being presented in this thesis.

CHAPTER 2

REVIEW OF LITERATURE

CHAPTER 2 REVIEW OF LITERATURE

The organized efforts of conserving and maintaining forests in India started during 1980 when the conservation policy was adopted. To adjust certain species and rehabilitate them suitably, the technique of *taungya* cultivation started during early part of this century. Gradually the need was realised for developing an ideal three dimensional ecosystem of trees/shrubs-grass-legume-animal (or soil-plant-animal system) under scientific management for optimum productivity and sustainability. Such a man made ecosystem covers three principal items: land and microclimate amelioration; animal feed, fuelwood, timber and occasional production of cash crops (Dalal, 1992).

In recent years, agroforestry/silvopasture has been developed as a science that promises to help farmers increase the productivity, profitability and sustainability of their land. In fact, it has evolved linking the survival with a system of diverse products through the experience of people. From a socio-economic perspectives, the silvopasture systems encompasses an immense social impact (FAO, 1978). Since 1970s there has been an increase in the recognition given to role of forests and trees in increasing agricultural productivity, human welfare, alleviation of energy problems and conservation of the environment. Initially, the goal of tree improvement for silvopasture was focused in increasing the effectiveness of land use for rural communities. In the modern context, however, attention has been paid to the efficient management of silvopasture which includes processing and marketing too. The increasing emphasis placed on scientific experiments and cash returns, to a great extent, has helped to recognize value of the traditional systems which are related to management and household survival (Turbull, 1984).

In India, silvopasture research was initiated during the early sixties at the Central Arid Zone Research Institute (CAZRI), Jodhpur. This institute worked out the technologies for establishment of shelter belts, stabilization of sand dunes and

development of agri-silviculture systems. Later on comprehensive studies on such systems were taken up around 1970s at Indian Grassland and Fodder Research Institute (IGFRI), Jhansi. The studies included on designing and development of silvopastoral systems on degraded lands with special emphasis on fodder production one hand and the conservation on the other hand. Gradually the other institutes *viz.*, Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehra Dun and Central Institute for Dryland Agriculture (CRIDA), Hyderabad initiated work on such systems to develop appropriate land use system in their respective regions. Besides these, an All India Coordinated Research Project on Agroforestry (AICRPAF) with 20 centres was initiated by ICAR during the year 1983. Silvopasture research in India was further strengthened during the seventh plan (1985-90) by adding 11 more centres to the AICRPAF and by creating a National Research Centre for Agroforestry (NRCAF) at Jhansi during the year 1988. Now studies on various aspects of silvopastures are also undertaken by most of the State Agricultural Universities (SAUs) and some traditional universities as well.

System Productivity

Pasture Production

Singh and Puri (1975) evaluated productivity of *Acacia nilotica*, *Cenchrus ciliaris* and *Dichanthium annulatum* based silvopastoral system in the ravine areas around Agra. During the end of five years, *C. ciliaris* gave peak yield of 3.93 t DM/ha/yr in the 18x18 m tree spacing treatment while *D. annulatum* gave peak yield of 3.55 t DM/ha/yr in 9x9 m tree spacing treatment.

Paroda *et al.* (1977) studied compatibility of *Cenchrus ciliaris* with *Acacia tortilis*, *Colophospermum mopane* and *Leucaena leucocepala* at CAZRI, Jodhpur. They found highest survival in *A. tortilis* (98.5 %) followed by *L. leucocephala* (68.1 %) and *C. mopane* (26.7 %). The dry forage yield of grass ranged between 1.0 – 1.7 t DM/ha.

Grass production in 14-18 year old plantation of four desert trees was monitored by Ahuja *et al.* (1978) in arid situation. The peak forage yield was reported under *Prosopis cineraria* (1.54 t DM/ha) and the least production was under *Acacia senegal* (0.69 t DM/ha). The increase in grass yield was attributed to increase in organic matter and increased availability of nutrients under *P. cinerarea.*

Deb Roy *et al.* (1978) studied the forage production of *Cenchrus ciliaris* and a mixture of *Chrysopogon fulvus* + *Sehima nervosum*, under different tree spacings of *Hardwickia binata* and *Albizia amara* from a typical degraded site in Bundelkhand. Forage production from the mixture of *C. fulvus* + *S. nervosum* (4.23 t DM/ha) was higher than that of *C. ciliaris* (3.74 t DM/ha).

Similarly, Roy *et al.* (1984) studied forage production of *Cenchrus ciliaris*, *Chrysopogon fulvus*, *Stylosanthes hamata* and *Macroptilium artopurpureum* in association with *Dicrostachys cinerea* on a highly calcareous wasteland site in this region. Peak forage yield was recorded in case of *Cenchrus ciliaris* (4.73 t DM/ha) followed by *Stylosanthes hamata* (3.92 t DM/ha), *Chrysopogon fulvus* (2.21 t DM/ha) and *Macroptilium artopurpureum* (1.57 t DM/ha).

Deb Roy (1986) reported higher pasture production from *Sehima nervosum* (7.8 t DM/ha) and *Chrysopogon fulvus* (7.4 t DM/ha) than from *Cenchrus ciliaris* (5.7 t DM/ha) in the third year of establishment in association with *Albizia lebbek* on a typical Bundelkhand wasteland with semi rocky substratum. At a similar such site, the mixture of *Cenchrus ciliaris* and *Dolichos axillaris* gave peak forage production of 7.9 t DM/ha in association with *Albizia procera* whereas *Chrysopogon fulvus* provided forage production of 6.0 t DM/ha in association with *Prosopis juliflora.*

Konwar *et al.* (1989) studied forage production from *Stylosanthes hamata* and *Cenchrus ciliaris* in association with *Leucaena leucocephala* planted in contour furrows spaced 7.5 m apart. The pasture production under *L.*

leucocephala + *S. hamata* system was more productive (4.15 t DM/ha) than *L. leucocephala* + *C. ciliaris* (2.48 t DM/ha).

Arya (1995) studied mean dry grass production of 81.95 q/ha under *Poplar* plantation at 4x7 m spacing, whereas under *Eucalyptus* trees planted at 3x3 m spacing yield was only 14.92 q/ha.

Deb Roy (1989) studied average forage production (5 years) of *Cenchrus ciliaris* and *Cenchrus setigerus* in association with *Acacia tortilis* and *Leucaena leucocephala. Cenchrus ciliaris* in association with *Acacia tortilis* gave an average forage production of 3.5 t DM/ha while in association with *Leucaena leucocephala* it gave higher production (4.1 t DM/ha). In contrast, *Cenchrus setigerus* gave higher production (3.1 t DM/ha) in association with *Acacia tortilis* when compared to *Leucaena leucocephala* (3.0 t DM/ha).

Production from Tree

Roy and Deb Roy (1983) reported leaf fodder production of 10.2 kg/tree (4.0 t/ha) through one-third lopping of *Bauhinea purpurea* in alternate years. Lopping studies on two 6-7 year old *Albizia* species *viz.*, *Albizia lebbek* and *Albizia procera* grown in association with *Cenchrus ciliaris* + *Stylosanthes hamata* pasture revealed that the latter species gave not only higher leaf fodder production but also higher firewood production when compared to the former species. The mean green leaf fodder production of *Albizia procera* was 28.7 kg/tree (8.04 t/ha). The corresponding mean fuelwood production was 24.4 kg/tree (6.83 t/ha). Mean dry leaf fodder and fuelwood production was 15.6 kg/tree (4.37 t/ha) and 14.6 kg/tree (4.08 t/ha), respectively (Deb Roy, 1986).

Roy and Deb Roy (1986) reported that two-third lopping on an annual basis provided maximum and consistent fodder supplies from *Albizia amara* (Green: 10.95 t/ha, Dry: 5.59 t/ha). The corresponding green and dry firewood production were 17.84 and 10.2 t/ha, respectively. Biennial lopping on the other hand gave much lower production. Maximum green and dry leaf fodder and

fuelwood production of 8.6, 4.7 kg/tree and 13.7, 8.2 kg/tree was observed in case of two-third lopping biennially.

Gill (1986) studied fuel and fodder production under agroforestry system on cultivated land by using *Sesbania grandifolia* as tree component at IGFRI, Jhansi. Maximum fuel produciton (3.75 t DM/ha) was registered with the pure *Sesbania* plantation treatment, closely followed by the *Sesbania* and *Nandi* grass treatment (3.73 t DM/ha).

Singh (1988) have observed that silvopastoral technology is successful in areas with less than 1000 mm. rainfall, with a dry season for nine months. It has potential to produce 3.0-7.5 t/ha/yr fodder and 4.5-6.0 t/ha/yr firewood. In multi tiered system an additional grain yield of 0.6 t/ha/yr can also be obtained.

Swaminathan and Ravindran (1989) have studied the biomass production of four tree species for use in dry zone silvopasture system. It was found that *Dalbergia sissoo* had the highest ratio of forage (twigs and leaves) to the total biomass produced (20.30 %) followed by *Hardwickia binata* (18.77 %), *Leucaena leucocephala* (16.68 %) and *Albizia* (10.79 %). But in terms of the unit production of forage, *L. leucocephala* was found to have the highest forage productivity (4.036 t/ha) followed by *Albizia* (0.588 t/ha), *Hardwickia* (0.480 t/ha) and *Dalbergia* (0.358 t/ha).

Rai *et al.* (1983) reported woody biomass production varying from 14.6 to 25.7 kg/tree in a medium to high diameter class under silvopastoral system at 3.5 years for *Sesbania grandifolia* whereas for *Sesbania sesban* it varied from 9.2 to 23.2 kg/tree grown at a spacing of 5x2.5 m.

Deb Roy and Gupta (1984) reported bole and branch wood production from 13 years old *Acacia tortilis* plantation under silvopastures at Jhansi. Maximum production of 117.6 kg/tree bole and 245.9 kg/tree branch (total wood production 363.6 kg/tree or 93.14 t/ha) was recorded in wider tree spacing in association with *Cenchrus ciliaris*. This was followed by 77.47 t/ha in narrower tree spacing in association with *Cenchrus setigerus*. Thus, mean wood production

was 57.50 t/ha (4.47 t/ha/yr). Muthana and Arora (1980) reported wood production from a 12 years old pure plantation of *Acacia tortilis* in arid region. The production was 53.6 t/ha in 3x3 m spacing and 39.2 t/ha in 6x6 m spacing.

Deb Roy (1988) reported woody biomass from a 9 years old *Albizia lebbek* plantation raised on a typical semi-arid wasteland of Bundelkhand. The mean biomass of 154.84 kg/tree was reported. The mean bole wood production was 77.86 kg/tree (varying from 49.6 to 96.2 kg/tree). Kalla *et al.* (1978), however, reported total wood production of 15.1 kg/tree from a 14 years old plantation of *Albizia lebbek* in arid Rajasthan.

Desale *et al.* (1990) reported that *Leucaena* in a agroforestry system, planted at 90x90 cm spacing and harvested for dry wood at the age of four years, produced 291.58 t/ha of dry wood whereas *Eucalyptus* planted at 60x60 cm spacing and harvested at the age of four years, produced 109.27 t/ha. As regards the coppice yield, *Eucalyptus* at the age of four years (spacing 30x30 cm) yielded maximum fuel (155.81 t/ha) when compared to the coppice yield of *Leucaena*, planted at 90x90 cm (123.20 t/ha).

Pathak *et al.* (1992) have studied tree productivity of a 15 year old *Albizia lebbek* trees (density 400 trees/ha) in silvopastoral system. From such a system 32.98 t/ha oven dry wood with an annual increment of 2.9 t/ha was reported. Parrotta (1989), however, reported wood production of 29.5 t/ha at 3 years from a high density plantaiton of *Albizia lebbek* (10000 tree/ha) in Puerto Rico (1700 mm rainfall).

Gupta and Pathak (1994) studied the wood produciton of *Faidherbia albida* under silvopastoral system at 9 years of growth at Jhansi. The total biomass production was 41.8 t/ha of which 40.5 t/ha was wood. The production of bole was 23.1 t/ha while the branch was 17.4 t/ha.

Singh and Sengar (1994) reported the woody biomass production in an age series plantation of *Dalbergia sissoo* in Orai Forest Division, northern part of the Bundelkhand region in Uttar Pradesh. On area basis, maximum biomass was

recorded in bole (155.04 t/ha) followed by branch (110.85 t/ha) from the 19 years old stand.

Raizada and Rao (1994) reported the biomass production and its distribution among different tree components, in an age series of *Eucalyptus* hybrid plantation in a red soil watershed at Chitradurga, Karnataka. The total aboveground biomass production ranged from 5 t/ha (6 years) to 11.32 t/ha (14 years). The contribution of bole bark biomass to total above ground biomass decreased from 67 per cent (6 years) to 64 per cent (14 years). However, the contribution of branch biomass increased from 12 per cent (6 years) to 16 per cent (14 years).

Microclimate

Climate is one of the principal environmental factors which influence the interaction of biological organisms and impose many of the primary tolerance limits in the selection of the species capable of surviving in a given area. In the arid and semi-arid regions, for many ecological regions, forestry as a method of land use has gained acceptability. Of the various microclimatic parameters, knowledge of the incidence of radiation and its interception by the forest canopy, the temporal variations in air temperature, soil temperature, relative humidity, wind speed and interception of rainfall by the canopy structure are of great importance in the silvopastoral and agroforestry systems as they decide the suitability of a particular crop or grass to be introduced into the forest ecosystem (Ramakrishna, 1984; Ong, 1991).

Studies carried out in a 7 years old *Acacia tortilis* plantation during the monsoon season at Jodhpur showed that during the morning hours air temperature beneath the tree canopy was lower by 0.1 °C to 0.7 °C than those recorded in the open, while during the afternoon period the temperatures underneath the tree canopy remained lower by as much as 0.6 °C to 2.0 °C than those recorded in the open (Ramakrishna and Sastri, 1977).

Ramakrishna and Sastri (1977) studied soil temperature in an agroforestry system involving *gaur* and *Acacia tortilis* (7 years old) at Jodhpur. In the *kharif* season, the mean daily maximum soil temperature beneath the tree cover was lower by as much as 10 °C to 16 °C in the top soil zone (0 - 5 cm) and 4 °C to 5 °C at 30 cm depth than those recorded in the open, which indicates a better soil thermal regime under the tree plantation.

Singh *et al.* (1980) assessed the effect of tree shade (full shade, partial shade and open area) on forage yield in a grassland planted with *Acacia catechu* and *Dalbergia sissoo* in north India. They noticed that forage yield was significantly higher in open than under partial shade or full shade. Average yield and clump diameter of grasses under partial shade of tree crowns edges were 86.7 and 38.0 per cent, respectively of that in the open patches, while under full shade of crowns the figures were 58.4 and 29.4 per cent, respectively.

Ramakrishna (1984) studied the pattern of rainfall interception in *Acacia tortilis* and *Holoptelia integrifolia* plantation at Jodhpur. The rainfall interception varied between 23 to 33 per cent and 14 to 19 per cent, respectively under moderate to heavy rainfall conditions. The rainfall pattern was attributed to the canopy shape and density of plant cover in case of *Acacia tortilis*.

Studies on microclimate variations around the tree cover by Ramakrishna (1984) revealed that under 13 years old *Acacia tortilis* based silvopastoral system, the total incident radiation just beneath the tree canopy was only 14 to 30 per cent of that received in open areas. It was insufficient for good growth and productivity of pasture grasses like *Cenchrus ciliaris*.

Hazra and Patil (1986) studied light infiltration under four tree species *viz*., *Albizia lebbek*, *Albizia procera*, *Leucaena leucocephala* and *Acacia tortilis* at Jhansi. They found that light infiltration underneath the tree cover varied from 74 to 93 per cent of the PAR on open sites without trees. The tree cover also maintained higher air and leaf temperature when compared to open sites. Dry matter production by grasses under *Albizia lebbek*, *Albizia procera*, *Leucaena*

leucocephala and *Acacia tortilis* was 665, 621, 565 and 608 gm/m^2, respectively. In open sites the production was 660 gm/m^2. Igbounugo *et al.* (1986) also reported similar increase in productivity of grasses with increase in light intensity.

Misra and Bhatt (1990) studied interaction of infiltered light and canopy temperature on the productivity of grasses *viz.*, *Sehima nervosum* and *Heteropogon contortus* under the tree canopies of *Hardwickia binata*, *Leucaena leucocephala*, *Acacia tortilis*, *Albizia lebbek* and *Albizia amara*. *Acacia tortilis* and *Hardwickia binata* allowed 60 per cent and 55 per cent PAR infiltration of the total PAR whereas *Leucaena leucocephala* infiltered least amount of PAR (33 %). Higher canopy air temperature difference (-6.8 °C) was recorded under *Leucaena leucocephala*. About 98 per cent of dry matter yield of grasses was obtained under *Hardwickia binata* and *Acacia tortilis* canopy when compared with the dry matter yield in open field.

Nutrient Accumulation

The biomass, productivity and nutrient cycling in a 24 years old *Dalbergia sissoo* plantation have been studied by Sharma *et al.* (1988). It was found that out of the total above ground biomass of 162 metric t/ha, the roots contributed 15.4 per cent. Maximum concentration of nitrogen was observed in leaf and minimum in the bole. The highest concentration of Ca was found in bark and least in the bole. As compared with the annual uptake of nutrients, 63 per cent N, 50 per cent P, 48 per cent K, 67 per cent Ca and 57 per cent of Mg were returned to the soil annually through litter fall.

Singh *et al.* (1993) reported biomass and nutrient (Ca, Mg, Na, K, P) distribution in the different components (leaves, branches, stems and roots) of six tree species in plantations of different ages (*Tectona grandis*, 30 yr old; *Dalbergia sissoo*, 19 yr old; *Emblica officinalis*, 9 yr old; *Eucalyptus hybrid*, 7 yr old; *Acacia auriculiformis*, 7 yr old; *Hardwickia binata*, 19 yr old) on the *Bhata* soils of Raipur. Biomass was comparatively higher in *E. tereticornis* (26.74 kg/plant),

A. auriculiformis (6.49 kg/plant), *H. binata* (36.45 kg/plant) and *P. emblica* (13.49 kg/plant) than in *T. grandis* (11.34 kg/plant) and *D. sissoo* (29.65 kg/plant). Nutrient content was higher in the leaves and lower in the roots of all species.

Singh (1994) have studied the pattern of biomass and nutrient accumulation in eight stands of *Cryptomeria japonica* (7-40 years old) in the Darjeeling Hills. The above ground biomass varied from 5.5 to 158.0 t/ha. The highest concentration of most of the nutrients was found in the leaf. Nutrient concentrations of Ca (2.9 %) and N (2.3 %) were higher when compared to the nutrient concentration of P (0.022 %). Nutrient accumulation and biomass increased with age of stand but their proportion in aerial components of plants was greater in the young stand as compared to the mature stand. In early stages of stand development Ca was higher than N. The nutrient pool in standing crop biomass of the oldest stand was nearly 698 kg Ca, 422 kg Mg, 363 kg K, 67 kg Na, 117 kg N and 55 kg P per ha and their accumulation efficiency followed a similar pattern to that of biomass and nutrients with respect to stand age.

Negi *et al.* (1995) have reported the biomass and nutrient distribution of 10, 20 and 30 year old plantations of teak (*Tectona grandis*) in *Tarai* region of Uttar Pradesh. The total standing biomass of these stands increased with the increae in age/diameter (74.5 t/ha in 10 year stand to 164.1 t/ha in 30 year stand). Maximum amount of N, P and Mg was accumulated in the bole while higher accumulation of Ca was observed in bark and roots. Harvesting of only utilisable biomass (148 t/ha) at the age of 30 years was found to deplete 247, 41, 170, 632 and 198 kg/ha of N, P, K, Ca and Mg, respectively.

Adu-Aning *et al.* (1995) reported the above ground biomass and nutrient content from 34 year old *Anogeisus leiocarpus*, 16 year old *Tectona grandis* (teak) and 10 year old *Azadirachta indica* (neem) grown in the Sudan savanna, Ghana. The mean tree biomass increased from 7.7 kg in neem through 8.6 kg in *T. grandis* to 29.0 kg in *A. leiocarpus* after 10, 16 and 34 years, respectively. A

similar trend was recorded for the stand biomass as it was in the mean tree; neem with 400 trees/ha produced a stand biomass of 1391.2 kg/ha, teak 9529.8 kg/ha from 1625 trees/ha while *A. leiocarpus* produced the highest biomass of 45591.6 kg/ha from 1725 trees/ha. The concentrations and accumulations of N, P, K, Ca and Mg in the various above ground portions of the neem tree and stands of the *A. leiocarpus* were in the order of Ca>N>Mg>K>P, in teak; Ca>K>Mg>N>P, in neem; and Ca>K>N>Mg>P in *A. leiocarpus*. The concentrations of all the elements were highest in the leaves.

Tandon *et al.* (1996) have studied the biomass and nutrient accumulation in different age series of 4, 6, 8 and 10 years of *Eucalyptus hybrid* plantation at *Tarai* region of Uttar Pradesh. The total above ground biomass at 4, 6, 8 and 10 years were 20, 35, 89 and 138 t/ha, respectively. The total amount of nutrients accumulated in the above ground biomass ranged 78.4 kg/ha to 341 kg/ha in N; 1.9 kg/ha to 95 kg/ha in P; 36.8 kg/ha to 198.7 kg/ha in K; 69.9 kg/ha to 293.1 kg/ha in Ca and 25.4 kg/ha to 139.5 kg/ha in Mg from these plantations. Maximum amount of P, K and Mg was accumulated in the bole while maximum Ca was held up in bark at all ages. Accumulation of N was higher in leaf in younger plantations but as the stand reached maturity, higher accumulation of N was observed in the bole.

Nutrient Turnover

The phenomena of litter fall, decomposition and nutrient release are universal in all kinds of biomes and ecosystems but their productivity, extent and pattern differ widely in different phytoclimatic belts and under the dominance of different plant species. Litter production and decomposition from the vairous ecosystems of the world have been studied by a number of workers (Bray and Gorham, 1964; Swift *et al.*, 1979; Vogt *et al.*, 1986).

Egunjobi (1974) studied the range of annual litter fall and nutrient returns in an age group of 5-7 years of teak plantation in Nigeria. He found the annual

litter fall in the range of 8.4 to 10.0 t/ha. Nutrient return on an annual basis was in the range of 78-101 kg/ha for nitrogen, 8.5-10.4 kg/ha for phosphorus and 188-210 kg/ha for calcium. Similarly, Lundgren (1978) has reported annual litter fall of 6.2 t/ha from 18 years old pine plantation in Tanzania. The annual nutrient return of nitrogen, phosphorus and calcium was of the order of 41.0, 2.0 and 48.0 kg/ha, respectively in such system.

Studies on litter production and nutrient return through litter fall carried out in *Eucalyptus tereticornis* plantation (5, 7 and 10 years old; density 1167, 1176 and 1133 trees/ha, respectively) have shown that these stands produced total litter in the range of 3377, 3801 and 6207 kg/ha, respectively. The amount of various major nutrients returned to the soil through litter were found to be 30-59 kg/ha of nitrogen, 2-4 kg/ha of phosphorus, 15-31 kg/ha of calcium and 5-9 kg/ha of magnesium. The major proportion of all the nutrients was contributed by leaf litter followed by twig and bark litter (George, 1979).

Singh and Ambasht (1980) have studied the production and decomposition of litter in a poorly growing 13 years old *Tectona grandis* plantation at Chandraprabha Sanctuary, Chakia Hills, Varanasi. They have found an annual litter fall of 1.57 t/ha of which maximum litter production was in the winter (1.13 t/ha). Leaf accounted for most of the litter mass. Most of the litter remained on the ground during the summer and rapid decomposition took place in the rainy season (0.94 t/ha) followed by the summer season (0.35 t/ha). In one year period more than 90 per cent litter disappeared and the rest was carried to the next year as forest floor litter mass.

Singh *et al.* (1980) studied litter production and turnover of organic matter in the tropical dry deciduous scrub forest of *Zizyphus jujuba* in the Vindhyan hills of Varanasi. The amount of litter produced increased with the passage of time in the protected stands from 101.5 kg/ha/yr in 1975-76 to 129.9 kg/ha/yr in 1976-77 and 167.63 kg/ha/yr in 1977-78. The leaf litter accounted for 78, 70 and 68 per

cent in the respective years, showing that there was a rise in the relative ratio of falling twigs and fruits in the *Zizyphus* stand.

Neil and Angelis (1981) observed little difference in litter fall between evergreen and deciduous species. Depending upon the number of trees per ha and age, litter fall varied from 0.5 to 6.5 t/ha/yr. On the dry weight basis leaf litter contained 0.5 to 1.5 per cent N, 0.05 to 0.15 per cent P, 0.25 to 0.75 per cent K, 0.25 to 1.0 per cent Ca and 0.1 to 0.2 per cent Mg. After decomposition a large proportion of these elements became available for plant growth.

Van den Beldt (1983) assessed litter fall of *Leucaena leucocephala* in Hawaii under stand densities ranging from 1000 to 4000 tree/ha. Average annual litter fall was about 8.54 t DM/ha. No significant effect of stand density on litter production was observed. The studies on nutrient recycling showed that 100 kg N, 7 kg P, 16 kg K, 200 kg Ca and 12 kg S were recycled on a per ha per year basis through such litter.

Kushalappa (1987) has reported the annual nutrient return through litter on an unit area basis (kg/ha) from 6 years and 12 years old plantation of *Eucalyptus* hybrid. The maximum nutrient return was that of Ca and N in both the age series (38.9 kg/ha of Ca, and 32.8 kg/ha of N in 6 year old stands; 37.4 kg/ha of Ca and 38.5 kg/ha of N in 12 year old stands). The minimum return was of P which was 0.28 kg/ha and 0.33 kg/ha in 6 and 12 years old stands, respectively. Leaf litter contributed the maximum per cent of total nutrients returned (97 % of N, 89 % of P, 93 % of K and Ca and 92 % of Mg in 6 years old stands; 95 % of N, 85 % of P, 85 % of K and Ca and 87 % Mg in 12 years old stands).

In one study quantity of litter, its chemical composition, nutrient addition and changes in chemical constituents of soil were assessed under agroforestry system involving *Populus deltoides* and *Eucalyptus* hybrid tree with aromatic intercrops of *Cymbopogon martinii* and *C. flexuosus* in *Tarai* tract (Kumaon) of Uttar Pradesh. On an average dry litter production of *P. deltoides* was 5.0 kg/tree/year, where as of *Eucalyptus* hybrid was 1.5 kg/tree/year. The litter of *P.*

deltoides contained 1.3 times more N and 1.5 times more P and K than that of *Eucalyptus* hybrid. Addition of N, P and K through *Populus* litter was 36.6, 91.6 and 69.9 per cent more than *Eucalyptus* hybrid litter, respectively. Under these two canopies, soil organic carbon content increased from 33.3 to 83.3 per cent, available P increased from 3.4 to 32.8 per cent and available K increased from 5.8 to 24.3 per cent over control (no tree canopy) in 0-15 cm layer. In general, *P. deltoides* plantation was superior to the plantation of *Eucalyptus* hybrid in enriching the soil (Anonymus, 1988).

Chaubey *et al.* (1988) reported the comparative studies of leaf litter production and nutrient return in teak plantations raised after clear felling of natural forests and in the adjoining natural forests in Madhya Pradesh. The leaf litter production was found to be greater in teak plantation than in the adjoining natural forests. At Bijawar forest area, the total leaf litter output in teak plantation (20-23 years old) and in its adjoining natural forest was found to be 5.76 t/ha and 3.18 t/ha, respectively. Similarly, at Kalpi forest area, the teak plantation (20-23) produced 7.91 t/ha litter as against 3.60 t/ha litter production in adjoining natural forest. The per cent concentration of nutrients (N, P, K and Ca) was also higher in leaf litter of the plantation area when compared to the natural forest area. The quantities (kg/ha) of N, P, K and Ca returned to the soils through leaf litter in teak plantation was 71.93, 21.87, 26.47 and 143.3 kg/ha, whereas in adjoining natural forests it was 29.2, 8.26, 16.52 and 56.55 kg/ha, respectively.

Studies on the leaf litter production of dry deciduous forest ecosystem of Gir (Gujarat) indicated that Chhodavadi (teak dominated) alone contributed major portion to the total litter production (3.68 t/ha). Other species which contributed to the litter production at various sites were *Acacia catechu*, *Anogeissus latifolia*, *Butea monosperma* and *Diospyrus melanoxylom*. The total leaf litter production of Eastern Gir Forest was 10.17 t/ha, and the peak period of litter production was the month of February (Pandit *et al.*, 1993).

Singh *et al.* (1993) observed the litter production and nutrient return in a tropical moist deciduous forest (a *Grewia tillifolia/Dalbergia* community) in Coimbatore Forest Division in Western Ghat of Tamil Nadu. The annual litter production was 14220 kg/ha of which leaf litter was 10754 kg/ha. On an annual basis 238 kg/ha of N, 9 kg/ha of P and 89 kg/ha of K were returned to the systems through litter fall.

Varshney and Garg (1996) estimated the litter production in *Albizia lebbek* stand in sub-tropical climatic conditions. The average annual litter production was found to be 799.1 g/m^2. Contribution of leaves to the total annual litter production was maximum (569.89 g/m^2 or 71.3 %). This was followed by reproductive structures (171.89 g/m^2 or 21.5 %) and twigs (57.5 g/m^2 or 7.2 %).

Tandon *et al.* (1996) reported the litter fall and nutrient return in four different aged *Eucalyptus* hybrid plantation stand at Dehra Dun. A total of 4565, 5242, 10236 and 9952 kg/ha of litter were produced annually at the ages 4, 6, 8 and 10 years, respectively. Out of total litter, leaf litter contributed between 73 to 82 per cent, thus maximum nutrients were returned to the soil through leaf litter. Maximum return was observed for nitrogen followed by calcium, potassium, magnesium and phosphorus.

Gupta (1997) studied the litter fall and nutrient return in a 9 years old plantation of *Prosopis juliflora* in alkaline soils at Datia, Madhya Pradesh. An average annual litter fall of 4.98 t/ha was recorded. The amount of nutrients *viz.*, nitrogen, phosphorus and potassium added to soil through litter on an annual basis were 112, 8 and 55 kg/ha, respectively.

In a field study involving 8-9 year old woodlots of nine fast growing multipurpose tree species in Kerala, India the amount and release of nutrients through litter fall was studied by Jamaludheen and Kumar (1999). The average annual litter production was highest for *Acacia* (12.69 Mg/ha/yr) followed by *Paraserianthes* (9.17 Mg/ha/yr) and the lowest for *Pterocarpus* (3.42 Mg/ha/yr). Other MPTS showed a decreasing trend in the order: *Casuarina*> *A.*

heterophyllus> Emblica> Leucaena> Ailanthus> A. hirsutus. Nutrient accretion through litter fall accounted for about 38-203 kg N/ha/yr, 0.8-6.0 kg P/ha/yr and 3.4-15.7 kg K/ha/yr, respectively.

Soil Fertility Changes

Yadav and Singh (1970) studied effect of forest plantation on an alkali soil near Aligarh. They observed a decrease in the pH value and soluble salt content and an increase in the amount of organic matter and nitrogen in the upper 15 cm layer under *Prosopis juliflora.* The soluble salts increased to some extent below 15 cm depth which was presumably due to their downward translocation through leaching as a result of improved soil permeability.

The studies conducted by Aggarwal *et al.* (1975) on soil physico-chemical changes under 12 year old tree plantation in western Rajasthan showed that organic matter, total nitrogen and P_2O_5 was highest under *Prosopis cineraria* at 0-15 cm depth compared to the other trees such as *Acacia senegal*, *Albizia lebbek*, *Prosopis juliflora* and *Tecomela undulata* on bare site. This was also reflected in the higher number of hebaceous plant species (/m^2), mean plant density (/m^2) and mean above ground phytomass (g/m^2) under *P. cineraria* when compared to other species.

In a study on the ameliorative role of mesquite (*Prosopis juliflora*) plantation, Virginia and Jarrel (1983) found that N (both nitrate and ammonical), organic carbon, $NaHCO_3$, extractable P and saturation extract K were significantly higher in the soil beneath mesquite. However, the differences in pH, osmotic potential, saturation per cent and sulphate content were not significant. They concluded that woody legumes can fix nitrogen symbiotically and also add others nutrients in the surface beneath the canopies which may be important in maintaining the long term productivity of desert ecosystem. Considerable increase in organic carbon and available nitrogen content under mesquite plantations in highly alkaline soils in India has also been reported by Gill (1985).

Pathak and Gupta (1987) reported that organic matter addition through leaf litter in a two year old plantation of *Leucaena leucocephala* was in the range of 5.6 t/ha which improved soil tilth, cation exchange capacity, water holding capacity, bulk density besides reducing soil pH from alkaline to normal.

Chakrabotry and Chakraborty (1989) reported increase in organic carbon, nitrogen, potassium, electrical conductivity and water holding capacity under the canopy of *Acacia auriculiformis* when compared to that in the open.

Jha (1995) studied soil productivity of silvopastoral system with *Napier* grass in association with *Leucaena leucocephala* at Ranchi. Increase in organic carbon (0.4 to 0.49 %), available phosphorus (29 kg/ha to 46 kg/ha), available potassium (152 kg/ha to 179 kg/ha) and pH (5.8 to 6.5) of soil were reported.

The soil properties, in general, improves with tree cropping as compared to non-tree situation. Hazra (1990) found that field capacity, wilting point, organic carbon, cation exchange capacity and available N and P contents of soils were greatly improved, whereas bulk density, pH and EC values were appreciably decreased under *Albizia lebbek* plantation as compared to normal cropping. The canopy structure and also the type of tree species influenced the grass production underneath. The leguminous shrubs and trees had great influence in building up soil organic matter (0.32 to 0.91 %), available soil nitrogen (131 to 293 kg/ha), available phosphorus (6.2 to 18.5 kg/ha) and field capacity (11 to 15.8 %).

Isichel and Muoghalu (1992) evaluated the effect of tree canopy on soil fertility in Nigerian Savanna. Soils under tree canopies were found to have significantly greater levels of organic matter, calcium, magnesium, potassium, total exchangeable bases, CEC and pH than those in open grasslands. Trees of 7 m or more in height had greater influence on soil properties than smaller trees.

In a study, Vadiraj (1993) showed the influence of *Casuarina equisetifolia* plantation (1-8 year old) on the soil characteristics (especially on fertility) in Karnataka. It was reported that with increase in the age of the *Casuarina* plantation soil fertility increased. The significant increase in pH from 5.12 to 6.80,

EC from 0.036 to 0.064 m-mhos/cm^2, organic carbon from 0.53 to 0.83 per cent, available P from 9 to 18.2 kg/ha, available K from 85 to 205 kg/ha, indicated that with the advance in the age of the plantation, there was a steady increase in the value.

The studies conducted on 20 years old tree plantation of *Acacia nilotica*, *Eucalyptus tereticornis*, *Prosopis juliflora*, *Terminalia arjuna* and *Albizia lebbek* in alkali soils at CSSRI, Karnal by Dagar *et al.* (1994) revealed that the decrease in soil pH was from 10.2 to 7.5. Simutaneously EC also decreased from 1.11 to 0.25. However, the organic carbon, P and K significantly increased from 0.22 per cent, 28 and 278 kg/ha to 0.85 per cent, 60-111 and 387-702 kg/ha, respectively.

Relative growth performance and soil enrichment potential of some nitrogen fixing trees (NFTS) were studied by Bhola (1995). The organic carbon, N, P, K, exchangeable Ca, Mg and Na as well as available Zn, Cu, Fe and Mn were appreciably higher and pH was lower under NFTS as compared to the open situation. Under each species with increase of peripheral distance (from tree trunk) the pH was more but all other parameters declined irrespective of the species.

Sharma *et al.* (1996) analyzed the soil profile under tree canopy and open field conditions. Better nutrient status in 0-20 cm and 20-60 cm soil depth was reported under tree canopy. The organic carbon, nitrogen and potassium (K_2O) in these profile depths was 0.15 per cent, 512 kg/ha, 309 kg/ha and 0.13 per cent, 522 kg/ha and 242 kg/ha, respectively under *Prosopis cineraria* canopy. In open situation, the value of organic carbon, nitrogen and potassium (K_2O) were 0.13 per cent, 449 kg/ha and 290 kg/ha and 0.13 per cent, 506 kg/ha and 295 kg/ha, respectively.

The studies conducted on 9 years old tree plantation of *Prosopis juliflora* on highly alkaline soils at Datia. (Madhya Pradesh) by Gupta (1997) reported a decrease in soil pH from 9.8 to 8.3 and EC from 1.8 to 0.60 (dSm^{-1}). Similarly, the organic carbon, available nitrogen and available potassium increased

significantly from 0.14 per cent, 132 and 186 kg/ha to 0.35 per cent, 210 and 214 kg/ha, respectively. However, there was little effect on available phosphorus from 6.64 to 6.83 kg/ha.

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 3 MATERIALS AND METHODS

The Bundelkhand Region

Bundelkhand region comprises some part of Uttar Pradesh (24°11'-26°27' N latitude and 78°34' E longitude) and Madhya Pradesh (24° 40'-26° 50' N latitude and 76° 80'-80° 50'E longitude). The total geographical area of the region is 71,618 square kilometer. The human population is over 12 million. The livestock population is 9.43 million comprising of 5.36 million cattle, 1.64 million buffaloes, 1.82 million goats, 0.42 million sheep and 0.2 million other animals (Tyagi, 1997).

The topography of the region is characterized by its smooth flat lands and intermixed undulating areas of varied slope (Singh, 1971). The rainfall varies between 750 mm in north west to about 1200 mm in south-west. About 90 per cent of the total precipitation is received between mid June to end September with occasional showers during winter months. The distribution of rainfall is often erratic and even wet months, July and August which receive about 70 per cent of the annual total, many a times experience long dry spells. May and June are the hottest months with maximum temperature of 43-46 °C. Minimum temperature of 3-4 °C is recorded during January. The area is termed as semi-arid with moisture index from -40 to -60 (Ghosh, 1991).

There are two major soil groups found in the region *viz.*, red and black (Singh, 1971). Red soils are coarse grained, upland soils and are found primarily in Jhansi and Lalitpur districts of UP. The black soils are heavy soils and are distributed in low lying areas of Jalaun, Hamirpur and Banda districts of UP. These major soil groups are further classified according to their texture and color into four distinct series namely *rakar* and *parwa* in red soil group and *kabar* and *mar* in black soil groups. About 56 per cent of the area of the region in under red soil group (Mannikar, 1981). In general, soils of this region are poor in nitrogen, low to medium in phosphorus and medium to high in potash. Many a times

different soils occur in a small area giving a typical mosaic appearance (Hazra, 1981). The region has natural and man made reservoirs besides river systems on which dams have been made at various places to provide irrigation through canals. Rivers like *Betwa, Ken, Pahauj* and *Dhassan* are important from the irrigation viewpoint (Singh and Singh, 1994).

Of the total geographical area, the net sown area in the region accounts for 43.2 per cent. About 29.8 per cent of net sown area is under irrigation. Well irrigation accounts for about 75 per cent of the total irrigated area of the region. The balance of 56.8 per cent of geographical area is occupied by forests, barren and uncultivated land, land put to non-agricultural use, cultivated wasteland, land under miscellaneous tree crops and grass, permanent pastures and other grazing and fallow lands. The forest area accounts for about 16 per cent of the geographical area (Ghosh,1991).

The natural vegetation of this region is tropical dry deciduous which shows its growth and species gradient from east to west and south to north (Champion and Seth, 1968). Selected areas in the forests are used for grazing by animals. Besides usual grazing areas, the forest department develops grass *birs* in areas not suitable for timber or firewood production and are situated within zones of high demand for fodder and grasses. After the harvest of mature grasses, these areas are open for stubble grazing within prescribed limit. The area under permanent pasture accounts for over 5 per cent of the geographical area. However, it has now decreased to a great extent due to transfer of such lands to landless persons. The area under miscellaneous tree crops and groves accounts for about 0.8 per cent of the georgraphical area. Such lands are used as a grazing ground as well as rest spot for the animals under scorching sun during summer and rainy season. Cultivated wastelands occupy over 8 per cent of the geographical area. Such lands are under continuous use for grazing. Fallow lands (current and old fallow) also constitute about 8 per cent of the geographical area. These lands, left uncultivated due to various reasons, are used for growing grasses

during rainy season. The area is either used for grazing or harvested grasses are conserved as hay for future use (Tyagi, 1988).

The Experimental Site

The study was carried out during January 1997 to December 1998 on a piece of degraded land at Central Research Farm of Indian Grassland and Fodder Research Institute, Jhansi (25° 27' N latitude and 78° 35'E longitude and about 275 m above sea level) (Fig. 1).

Present studies were undertaken to analyze silvopasture productivity of three different tree canopies (600, 400 and 100 trees/ha) and also of open situation (without any tree) in an ecosystem context.

Thus, for this study, The following four microsites were marked as under:

A. Microsite 1 (MS 1) - Open situation; only pasture situation.

B. Microsite 2 (MS 2) - Sparse/light canopy situation with about 100 trees/ha.

C. Microsite 3 (MS 3) - Medium canopy situation with about 400 trees/ha.

D. Microsite 4 (MS 4) - Dense canopy situation with about 600 trees/ha.

Climate

The study area represent a typical, semi-arid monsoon type of climate characterized by dry summer, hot rainy season, warm autumn and cool winter. The study period received average annual rainfall about 945 mm. Approximately 90 per cent of the total rainfall was received between July to September. January was the rainless month and February received very little rainfall (< 1 mm). May was the hottest month with mean maximum temperature (41.3 °C) followed by June (39.1 °C). January was the coldest month with mean minimum temperature of (5.6 °C) followed by December (8.0 °C) (Fig. 2). Table 1 shows some meteorological parameters during the study period. It is evident that relative humidity almost followed the pattern of rainfall and temperature. May shared lowest relative humidity (55/26) followed by June (64/37). The wind velocity was

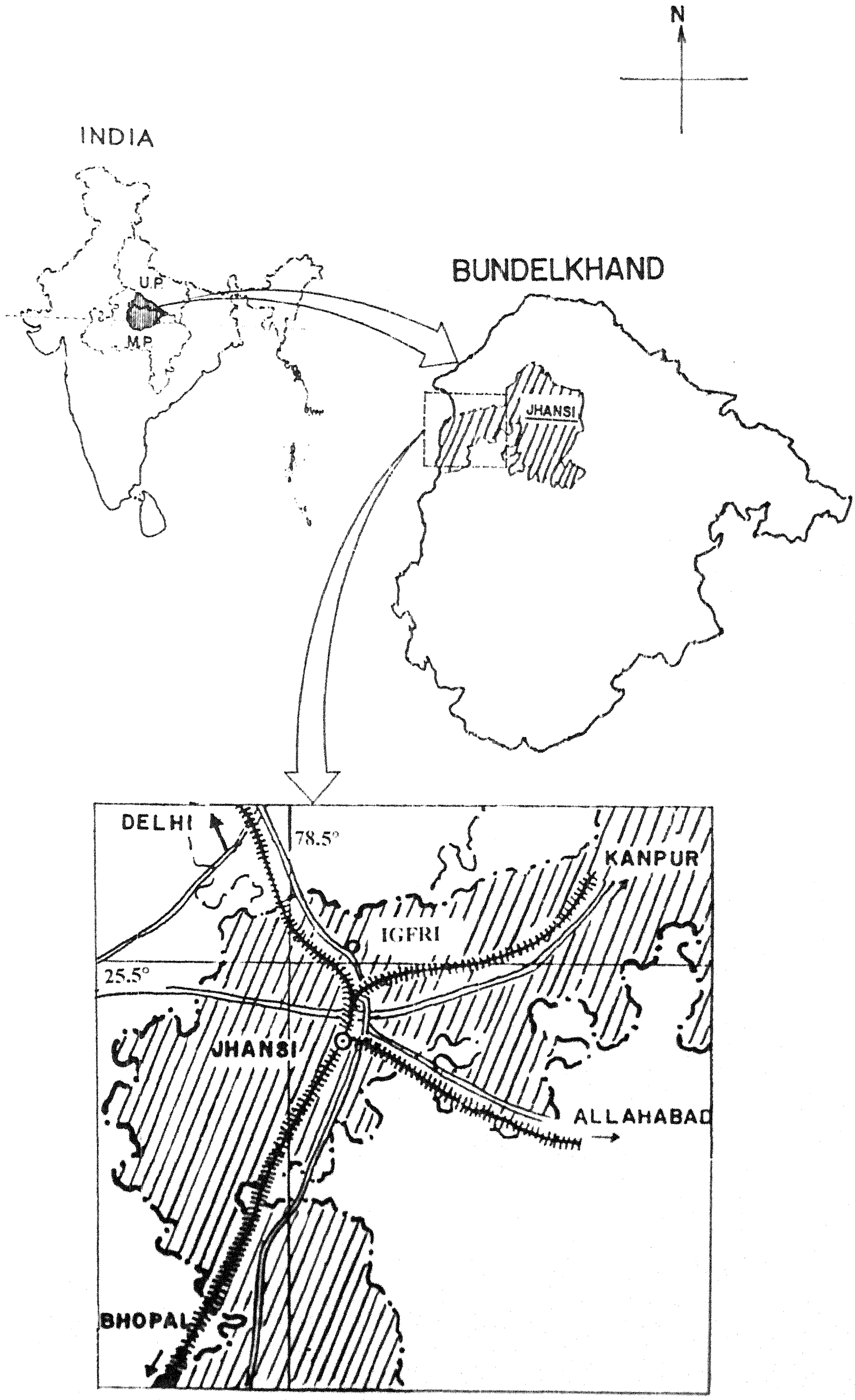
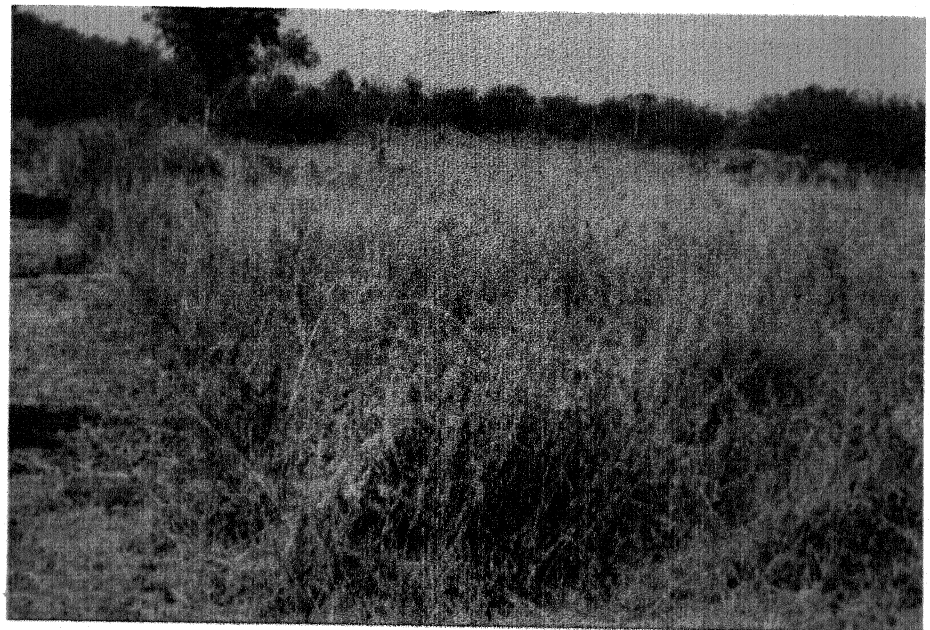


Fig. 1
Location of Bundelkhand region in India and the experimental site.

Plate 1

An outer view of the study site (*Albizia amara* stand in right)



A view of the only pasture situation (with out tree)

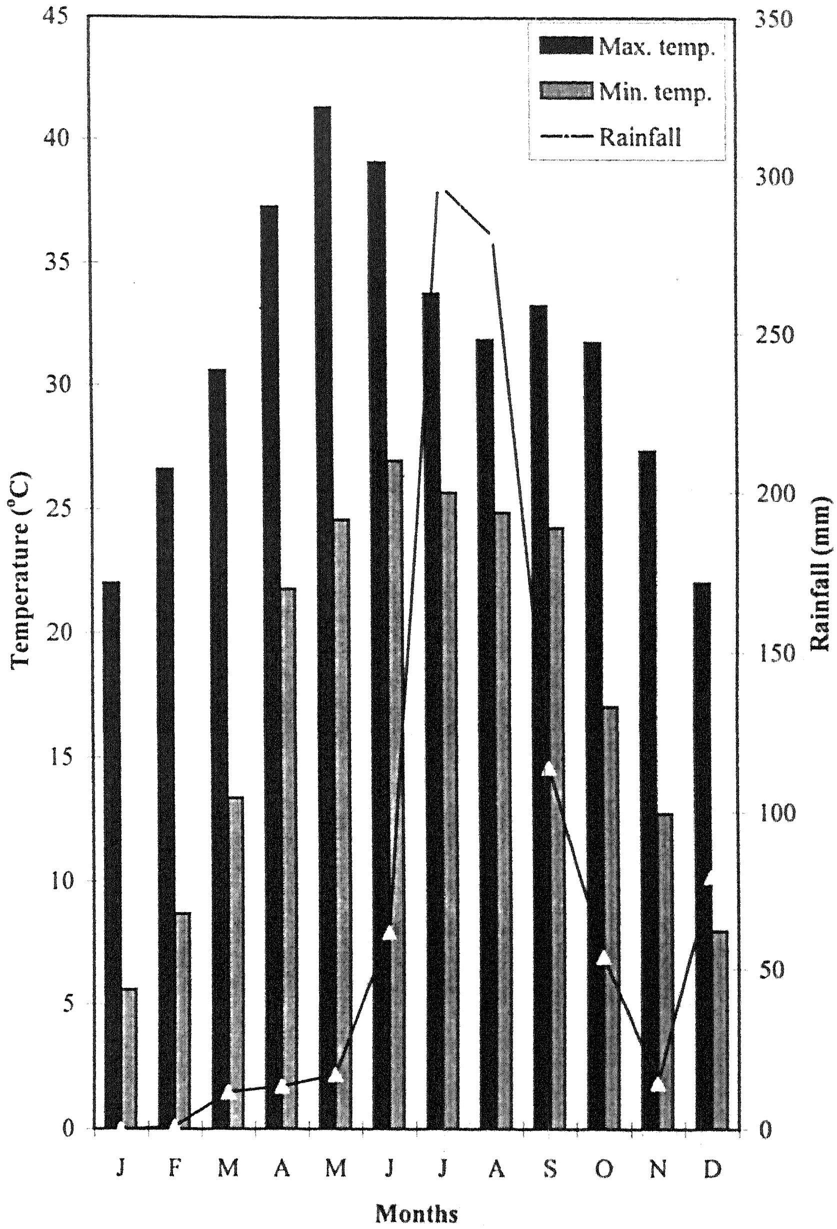


Fig. 2
Variation in mean monthly temperature and rainfall at the study site (1997-1998).

Table 1
Average meteorological parameters recorded at study site (1997-1998).

Months	Temp. (^{o}C)		RH (%) Period		Rainfall (mm)	Rainy days (No.)	Wind velocity (km/hr)	Bright sunshine (hrs/day)	Evaporation (mm/day)
	Max.	Min.	Ist	IInd					
Jan.	22.0	5.6	95	41	000.0	0.0	1.1	7.8	2.0
Feb.	26.6	8.7	91	32	000.9	0.0	2.5	9.4	3.6
Mar.	30.6	13.4	88	30	011.6	1.5	3.8	8.7	4.8
Apr.	37.3	21.8	68	25	013.4	1.5	3.9	9.7	7.5
May	41.3	24.6	55	26	017.0	2.5	6.8	10.2	11.5
June	39.1	27.0	64	37	061.8	6.0	7.6	8.0	10.5
July	33.8	25.7	87	64	297.5	13.5	5.5	4.4	4.4
Aug.	31.9	24.9	93	73	281.1	15.0	3.6	4.0	3.2
Sept.	33.3	24.3	91	62	113.9	7.5	1.8	7.6	4.0
Oct.	31.8	17.1	91	52	054.1	2.5	1.4	8.0	3.2
Nov.	27.4	12.8	92	47	014.5	1.0	1.3	7.0	2.3
Dec.	22.1	8.0	93	66	079.6	1.5	1.3	2.7	1.5

maximum during June (7.6 km/hr) followed by May (6.8 km/hr) and July (5.5 km/hr). It was least during January (1.1 km/hr).

Brightness or sunshine was most during May (10.2 km/hr) followed by April (9.7 km/hr) and February (9.4 km/hr). Brightness was least during December (2.7 hr/day). Peak evaporation was recorded during May (11.5 mm/day) followed by June (10.5 mm/day). The rate of evaporation was higher than rainfall during months of January and February. This shows droughtness due to higher evaporation need compared to rainfall receipt during these months.

Soil

The soil of the area was mainly red gravelly (alfisols) with good porosity and drainage and in some places it had semi-rocky substratum. The range and value of soil physical and chemical characteristics of the study site are given in Table 2. It was almost neutral with about 26.7 per cent water holding capacity. The soil nutrient status was in low to medium range (organic carbon 0.34 %, available nitrogen 0.006 % and available phosphorus 2.1 ppm).

The Plant Components

Tree

Albizia amara (Roxb.) Boiv. (Family - Leguminosae, Sub family - Mimosoideae) is an indigenous tree to India. It is commonly known as *Kala Siris* (Hindi), *Tugli* (Kannada), *Chikreni* (Telugu), *Unjai* (Tamil). The original home of this tree is from peninsular South Asia to tropical East Africa. In India, it commonly occurs in the dry mixed deciduous and thorn forests of the Deccan (Troup, 1921). It also occurs in dry regions of Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Madhya Pradesh and Uttar Pradesh (Ram Prakash *et al.*, 1991).

Table 2
Average soil physical and chemical characteristics at the study site.

Parameter	Range	Average
Texture		
Sand (%)	18.2 - 73.9	41.8
Silt (%)	21.9 - 37.8	23.4
Clay (%)	16.3 - 38.6	34.8
Bulk density (g/cc)	1.11 - 1.19	1.14
pH	6.65 - 7.05	6.85
Nutrients		
Organic matter (%)	0.9700 - 1.38	1.18
Organic carbon (%)	0.5700 - 0.79	0.69
Total nitrogen (%)	0.0890 - 0.127	0.13
Available nitrogen (%)	0.0390 - 0.048	0.040
Total phosphorus (%)	0.0030 - 0.007	0.0034
Available phosphorus (%)	0.0004 - 0.0008	0.0007
Total potassium (%)	0.1700 - 0.48	0.31
Total calcium (%)	0.2600 - 0.59	0.43
Available calcium (%)	0.1670 - 0.229	0.21

Botany

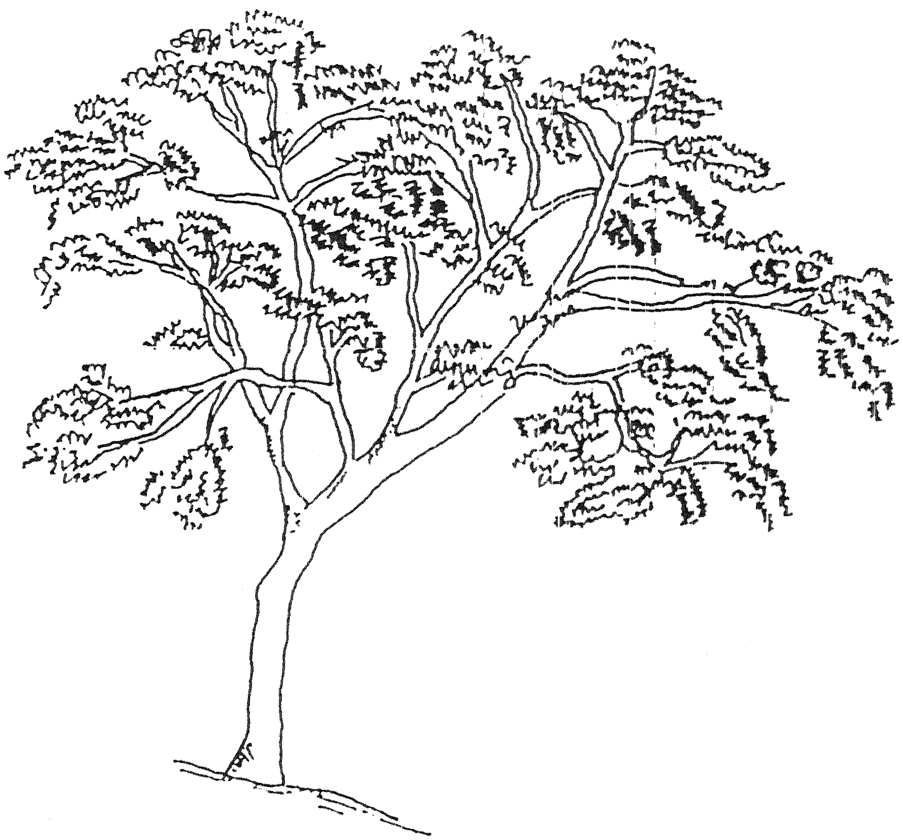
It is a small to moderate sized tree; 6 to 9 m in height, 60-90 cm in diameter, much branched, deciduous, having smooth dark green scaly bark (a diagnostic feature). The leaves are pinnately compound, with 15-24 pairs of small linear leaflets (1-2 cm x 2-6 mm) on 6-15 pairs of pinnae. The clusters of fragrant yellow globose flowers develop in April-May, when the tree is almost leafless. The pods are thin, flat, large (12-20 cm x 2-3 cm), greyish brown, veined with undulating edges, pubescent, 6-8 seeded, ripen and fall to the ground during November-December. Seeds are small, ovoid and flattened. There are about 14000 seed in one kilogram (Fig. 3) (Brandis, 1921; Hocking, 1993; CSIR, 1985).

Environmental Requirements

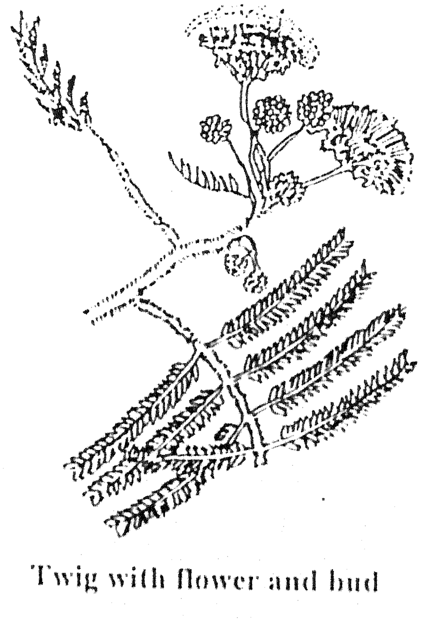
It is a strong light demander, intolerant of shade. It can tolerate maximum temperature in the range of 47 °C and mean daily minimum temperature not lower than about 10 °C. It cannot stand frost, but is drought and fire hardy when mature. It thrives in the rainfall range of 500-1000 mm. It grows successfully in various soils, common on rocky and shallow soils (Hocking, 1993).

Establishment

The natural regeneration capacity of the tree is good in areas protected from fire and grazing. Also, it has the ability to reproduce by self seeding and coppice management. For artificial propagation of this species, best method is through direct seeding at the start of monsoon rains. Seed treatment consists of immersion in boiling water for 5 minutes followed by soaking in cooling water for about 12 hours. Sowing for block plantations is usually along in lines (9-10 m apart) along the contours. Germination takes place within 7-10 days. Plants are thinned to 2-3 m in the first year and 5-8 m in third or fourth year depending on the growth rate. Young seedlings are required to be protected from fire and especially from grazing, as they are much relished by livestock (Hocking, 1993).



Tree



Twig with flower and bud

Pod

Fig. 3

Economic Uses

Wood

The wood is heavy (specific gravity 0.84; weight 865 kg/cubic m), straight-grained and medium-textured. Sapwood is white and heart wood light brown, often with a purplish cast mottled with dark and light shades. Growth rings are inconspicuous. The timber seasons well. It is very strong, moderately hard, work to a fine, smooth surface and takes polish well. The wood is used for tool handles, mallett heads and agricultural implements. It is commonly used for carving and turnery. It is also an excellent fuel wood. The calorific values of the sap and the heart wood are 5049 and 5306 kilo calories per kg, respectively. A pulp of high $\propto$-Cellulose content, purity and brightness is obtained from the heart wood by water pre hydrolysis sulphate process followed by multistage bleaching (Troup, 1921; Pearson and Brown 1932; Krishna and Ramaswamy 1932).

Fodder

The leaves are eaten by the cattle, goats and sheep from lopped branches, but are not particulary well linked by these animals as the trees are lopped only when more palatable fodder is not available. The flowers are preferred and are either picked from the ground after they are shed or eaten from lopped branches. Both leaves and flowers appear to have a high feeding value, with a crude protein content of over 26 per cent of the dry matter. Crude fiber figures are not very high, though they are less in the flowers than the leaves (Dougall and Bogdan, 1958).

Medicinal Value

The tree yields a good gum which has cooling properties and useful in erysipelas, eye diseases, inflammation and ulcers. The leaves are used in opthalmia and as a hair wash. The leaves are also used as adulterant for tea. The

flowers are considered a cooling medicine and are externally applied to boils, eruptions and swellings (Rama Rao, 1914; Witt 1916; Kirtikar and Basu 1935).

Miscellaneous

Thus, the tree is a good firewood species for arid/semi-arid regions. It can be used in shelter belts and windbreak systems and for afforestation of degraded areas in the dry and arid/semi-arid tracts. It is also used as an emergency cattle feed in various parts of the country. In southern Kerala, it is grown chiefly as green manure for rice and also used as an avenue tree (Witt, 1916; Bourdillon 1937).

Agroforestry Application

The species on account of its fast growth, tap rooting habit and nitrogen fixing ability has great potential in agroforestry/silvopasture systems on degraded lands. It is also a well suited species for silvopasture development in mixture with other fodder species. It has very high potential for afforestation programmes on degraded lands having semi rocky substratum (Singh, 1982; Skerman, 1987). It has been recommended as one of the major fast growing fodder-cum-fuel tree for the Bundelkhand region (Deb Roy, 1989).

Principal Enemies

Injuries

Fire causes extensive damage to regeneration of this species. The species is also liable to browsing damage by cattle, sheep and goats (Ram Prakash *et al.*, 1991).

Insects and Pests

Damage from insects and pests are not serious in this species. The available reports indicate that larvae of *Achaea janata* defoliate, *Bruchus oberatus*

damage the seeds in the pods and *B. schoderi* attack the seeds. *Sinoxylon conigerum* Gerst. has been reported to make the wood liable to tunnelling during monsoon (Ram Prakash *et al.*, 1991).

Diseases

Leaf rust caused by *Ravenelia* species is important seedling disease of *Albizia* species in India whereas *Endothella albiziae* is reported to cause defoliation of *Albizia* species in Africa, the Philippines and Pakistan (Sharma and Bhardwaj, 1988). Many rusts belonging to the genera *Ravenelia* and *Uredo* are recorded only on *Albizia* species (Gibson, 1975).

Pasture Grasses

***Cenchrus ciliaris* Linn.**

This genus belongs to the tribe paniceae in which the two flowered spikelets fall when ripe leaving no glumes. The spikelets are solitary and pedicels are never swollen (Skerman and Riveros, 1992) It is commonly known as buffel grass or *anjan* grass and is very palatable when young and remains fairly palatable at maturity. It makes reasonable quality hay when cut in early flowering stage. It s persistence, deep rooting habit, resistance to drought and trampling are the other main attributes (Skerman and Riveros, 1992).

***Chrysopogon fulvus* (Spreng) Chiv.**

It has densely tufted culms bearing long linear acuminate leaves. The species presents some difficulty for taxonomist owing to its variability not only in vegetative parts but also in the size of spikelets and anthers (Bor, 1960). It is commonly known as *dholu* grass. The grass is a valuable fodder and is cut just before flowering. It may also be used as a sand binder (CSIR, 1950).

***Dichanthium annulatum* (Forsk.) Stapf.**

It has slender erect culms, nodes usually bearded, two to four racemes, erect and rather close, pedunculate, first glume of the spikelet not indurate. Stalks of racemes hairy, pedicellate spikelet usually male or bisexual, sometimes neuter but with both glumes well developed and often with lemmas (Skerman and Riveros, 1992). It is quite a palatable grass and widely used as hay in India. It is widely adaptable, tolerant to alkaline soils and is effective in erosion control (Skerman and Riveros, 1992).

***Heteropogon contortus* (L.) Beauv. ex. Roem. and Schult.**

A caespitose perennial, the culms erect to 75 cm, branching above, leaf sheaths keeled, glabrous. Raceme solitary, 3.5-15 cm long with up to 10 pairs of awnless spikelets at base and an equal number of pairs above. Fertile sessile spikelets having awns 5-10 cm long. The grass is palatable in early vegetation stage but unattractive as it matures. Besides fodder its main attributes are hardiness, perenniality, tolerance to fire and ability to grow on poor soils (Skerman and Riveros, 1992).

***Sehima nervosum* (Willd.) Stapf.**

In this species culms are densely tufted with leaf blades upto 30 cm. Racemes solitary, 7-12cm long, sessile spikelets pale green, with long bristles from the upper glume, and an awn about 45 mm long from the lemma, pedicelled spikelets purplish (Skerman and Riveros, 1992). It is one of the most palatable grasses in India and disappears quickly under grazing. It is also one of the important grasses for hay making (Dabadghao and Shankarnarayan, 1973).

Methods

Soil Studies

The soil samples were taken from two different depths *viz.*, Depth 1 (0-15 cm), Depth 2 (15-40 cm). The samples were taken by post-hole auger. Before taking soil samples all plants were cleared on the land surface, except the roots and organic matter embedded in horizon A. The soil sample for analysis of texture and other physical parameters were taken in the beginning and at the end of the investigation.

The texture analysis was done by Bouyoucos Hydrometer method as prescribed by Piper (1966). Soil pH was determined by using digital glass electrode pH meter at 1: 2.5 soil-water ratio. Electrical conductivity from supernatant of the soil solution was determined by using a conductivity bridge. Soil moisture was observed by drying a known weight in a hot air oven (105 °C) till constant weight. Bulk density of soil was also determined following method outlined by Piper (1966).

Organic carbon was estimated by Walkley and Black's rapid titration method (Jackson, 1973). Total nitrogen was determined by Kjeldahl method while total phosphorus, potassium and calcium were determined by wet digestion method described by Jackson (1973). Phosphorus was estimated through the vanadomolybdophosphoric yellow colour method and intensity of yellow colour was read on Spectronic-20 at 470 nm against a blank sample. Potassium dihydrogen phosphate (KH_2PO_4) was used to develop standard curve for further calculations. The quantitative estimation of potassium and calcium was carried out by using the diluted stock solution into flame photometer. The amount of potassium and calcium was calculated from the standard curve prepared from potassium chloride and calcium chloride, respectively. Available nitrogen was determined following alkaline permagnate method described by Piper (1966). The available phosphorus was determined following Olsen *et al.* (1954). The intensity of blue colour was read at 660 nm on spectronic-20 against a blank. The amount

of available phosphorus was calculated from the standard curve prepared with $KH_2 PO_4$. The available calcium was determined by ammonium acetate extract method described by Piper (1966).

Microclimate Studies

The microclimatic parameters *viz.*, photosynthetically active radiation (PAR), air temperature, soil temperature and relative humidity (RH) were measured at fortnightly intervals on clear sky days. The PAR was recorded by Radio Quantum Photometer (LI -185B, USA). Air and soil temperatures were recorded by infrared thermometer and RH was measured by using a dial type self indicating hair hygrometer.

Plant Growth Studies

Tree Growth

Growth data were recorded at six monthly interval. Height was measured by a calibrated meter rod. Collar diameter (cd) was measured at the 5 cm of stem base and diameter at breast height (dbh) at 135 cm height above ground level with the help of a tree caliper. Canopy spread was measured by measuring tape. The mean annual increment (MAI) was also calculated following standard method (Mac Dicken *et al.*, 1991).

Pasture Growth

During September of each year ten quadrate (1 m^2) were taken randomly at each microsite. The constituent species (five perennial grasses, annual grasses, legumes and weeds) were listed and counted. In perennial grass, each tiller was considered as an individual plant. Observations were made on growth characteristics of perennial grasses at each microsites by measuring height, tussock diameter and counting number of tiller.

The height of plant was measured from the ground level to top growing points. The length and breadth of the tussock was measured and the average value was calculated to represent the diameter. The number of tiller per plant in grasses was counted just before each harvest.

Biomass Studies

Aboveground Biomass

Tree

Sample trees, representing different diameter classes across the study site, were felled during February/March in each year following methods prescribed by New Bould (1967). After felling, the main bole, leaves and branches were separated. The main bole was cut into 1 m long segments starting from the base. Fresh weight of bole, branches and leaves were recorded in the field. A 5 cm wide disc from each bole segment was taken and weighed separately. The discs were dried in a hot air oven at 60 °C till constant weight. The oven dried samples were weighed for dry matter determination. Similarly, samples from branches and leaves (about 100 g) were taken for determination of dry matter.

Pasture

The understorey aboveground biomass was recorded by harvesting the whole plot and then weighing the pasture (perennial and annual grass) and weed (including legume forbs) separately. Fresh weight of herbage composition were recorded in the field using spring balance. Samples (about 100 g) were taken and dried in hot air oven at 60 °C till constant weight. The oven dried samples were weighed for dry matter determination.

Belowground Biomass

Tree

The sample trees were excavated (up to 1.5 m) for belowground biomass studies. The total roots were taken out and washed with water and then exposed in sunlight for two hours to remove surface moisture. The tap root was cut into upper, middle and lower segment and their weight was recorded in field. Samples were taken from these segments in the form of disc for dry matter determination. The secondary and tertiary roots were also weighed. The samples were dried in a hot air oven (60 ^{0}C) till constant weight. The oven dried samples were weighed for dry matter determination.

Pasture

The belowground biomass of pasture was recorded by excavating monoliths (30 cm^3). The roots were washed with water then exposed in sunlight (2 hrs) for removing surface moisture. The grass roots and distributed tree roots were separated. The samples (about 100 g) were dried in a hot air oven (60 ^{0}C) till constant weight. The oven dried samples were weighed for dry matter determination.

Litter Production Studies

Litter production was estimated by collecting litter samples at fortnightly interval from a litter trap of painted steel wire net of $1m^2$ collecting area and 1.5 mm mesh size. The litter traps were placed tree's continuous canopy and were raised 6 inches above the ground level on wooden frames to permit drainage of water without any litter loss and to avoid the action of soil fauna and the effect of soil splash. Sides of wire net were surrounded with wooden frame of 15 cm height. The collected litter was weighed, air dried and stored in paper bags. At monthly interval, the litter was separated into leaf, branch and miscellaneous (pod, buds, flowers etc.) which were weighed separately. The litter of each

category was oven dried (60 ^{0}C) till constant for dry matter determination (Mc Shane *et al.*, 1983).

Plant Nutrient Studies

Oven dried and powdered plant and litter samples were taken for nutrient (N, P, K, Ca) analysis. Nitrogen content was estimated by following Kjeldahl method prescribed by Piper (1966). For estimation of phosphorus, potassium and calcium, 1 g of plant litter material was digested in 70 per cent perchloric acid on a hot plate till solution turned colourless. The contents were cooled and then volume was made up to 100 ml in a volumetric flask as stock solution. Phosphorus was estimated by the method prescribed by Jackson (1973) and the intensity of yellow colour was read on Spectronic-20 at 470 nm against a blank. Potassium dihydrogen phosphate (KH_2PO_4) was used to develop standard curve for further calculations. The quantitative estimation of potassium and calcium was carried out by using the diluted stock solution into flame photometer. The amount of potassium and calcium was calculated from the standard curve prepared from potassium chloride and calcium chloride, respectively.

Nutrient accumulation (kg/ha) in different plant parts and recyclable nutrients through litter were calculated by multiplying dry matter with average nutrient concentration.

Litter Decomposition

The studies on mass loss pattern of leaf litter of *Albizia amara* was conducted in laboratory and field conditions. The samples were air dried and weighed into 10 g working samples. These were then spread in 9x15 cm nylon net bags. In laboratory, the litter bags were surface buried in trays filled up with the soil from the respective field sites. These trays were then kept in a B.O.D. incubator (27 ± °C) under controlled RH conditions for 180 days. The trays were periodically watered to avoid complete dry condition. The bags were carefully

recovered after every 30 days up to 180 days. In field, the litter bags were buried in the respective microsites during January/February 1997 at 1-2 cm depth. The bags were carefully recovered after every 3 months.

After recovering the bags, the remaining litter was air dried and weighed after removing the adhered soil particles etc. The nutrient analysis was done as per the standard procedure mentioned earlier. The nutrient release was calculated based on the per cent of nutrient in the initial litter content (Gupta and Singh, 1977).

CHAPTER 4

RESULTS AND DISCUSSION

CHAPTER 4 RESULTS AND DISCUSSION

PART I

MICROCLIMATE

Climate is defined as the mean or average condition of the atmosphere, that is, the mean or average weather (Rosenberg, 1986). However, more inclusively, it is not only the mean weather but also a typical variability and the range of extreme exhibited by the state of the atmosphere in a particular area over a specific period of time. Climatic description, therefore, need to be framed over specific timed periods (anywhere from hours to centuries) for specific location (Griffiths, 1985). The applicability of different agroforestry/silvopastoral systems at any location depends on the atmospheric processes at these levels, from a macro scale monsoons to micro scale shading of adjacent crops/pasture (Miller, 1993).

The chief environmental factors of aerial environment of plants include solar radiation (light), temperature (air and soil), humidity and soil moisture. These are being discussed for the four microsites selected for this study.

Solar Radiation (Light)

One of the major controls of microclimate in agroforestry/silvopastoral systems is solar radiation. It is also the one that is subject to considerable control by men (Reifsynder, 1989). Photosynthetically active radiation (PAR) is defined as that part of electromagnetic spectrum with wavelength between 400 to 700 nm. It is that part of sun's energy that is trapped by green plant and upon which all life ultimately depends.

It is, therefore, extremely useful to know how the canopy of woody and non-woody components in silvopastures intercept this radiation. By knowing how much is intercepted one can calculate the photosynthetic efficiency of this system

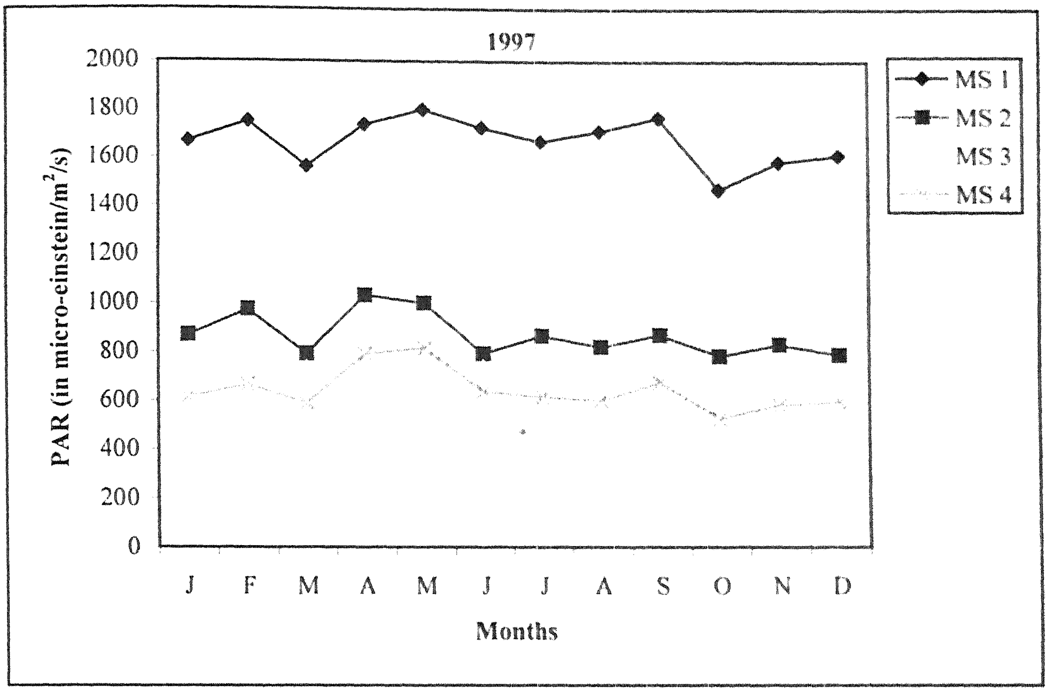
and match this against alternative canopy structures or theoretical models (Jackson, 1989).

The pattern of PAR availability to the pasture in different microsites during 1997 and 1998 is shown in Fig. 4. In open situation, peak values were recorded in May in both the years. Higher radiation was recorded in 1998 (1987 micro-einstein/m^2/s) when compared to 1997 (1800 micro-einstein/m^2/s). Highest mean annual PAR availability was recorded in open situation followed by light, medium and dense canopies of *Albizia amara* in both the years. In both the years the critical difference in PAR availability between open and under trees was significant. However, under trees, significant difference was found only between light and dense canopies. The average reduction in PAR availability was found to be 34.4 per cent, 43.3 per cent and 47.5 per cent, respectively under light, medium and dense canopies of *Albizia amara* (Table 3).

Table 3
PAR availability under open and different canopy situations of *Albizia amara* (annual average) (in micro-einstein/m^2/s).

Canopy	1997	1998
Open	1671±98	1565±285
Light	869±86	1026±159
Medium	762±100	887±144
Dense	644±84	822±134
	188	186

In agri-silvicultural study at IGFRI, Jhansi Hazra (1985) reported that moderate sized and spaced trees of *Albizia lebbek* allowed 80 per cent of PAR to underneath crops followed by *Acacia nilotica* (66 %) and *Leucaena leucocephala* (58 %). In another such study at IGFRI, Jhansi Hazra and Tripathi (1986) reported



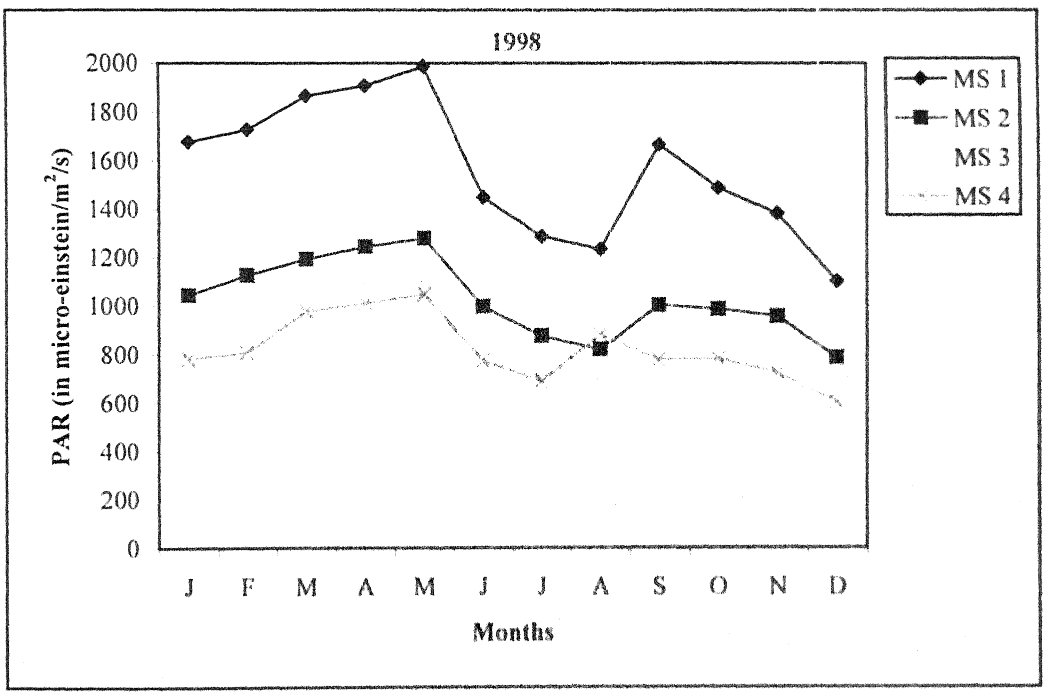


Fig. 4
Pattern of PAR availability to the ground vegetation at the four microsites of study (January-December).

that moderate sized and spaced tree of *Hardwickia binata* allowed 80 per cent PAR as compared to the open situation. This was followed by *Acacia tortilis* (65 %) and *Leucaena leucocephala* (48 %). In a silvopastoral study at IGFRI, Jhansi Misra and Bhatt (1992) reported least PAR infiltration from well established and closely spaced trees of *Leucaena Leucocephala* (30 %) the other species *viz.*, *Albizia amara*, *Albizia lebbek*, *Hardwickia binata* and *Acacia tortilis* infiltered 35 per cent, 37 per cent, 55 per cent and 60 per cent PAR, respectively.

Transmission of solar radiation through tree canopy depends on stand density but this relationship is not exactly linear in temperate species. A stand with 50 per cent of crown volume transmit less than 20 per cent incident solar radiation. With only 10 per cent of crown closure, certainly a rather a open stand, radiation is reduced by 25 per cent. Thus, is might be expected that even sparse stands would offer considerable protection from excessive radiation loads. On the other hand, crown closure of only one third could reduce solar radiation beneath by two third which may results into little radiation for some crops (Miller, 1959). It is, however, expected that in tropics where sun is close to zenith at noon, the rilationship between transmitted light and crown closure would be close to linear (Reifsynder, 1989). Similar type of relationship has been observed in this study.

However, this situation is for direct and diffused solar radiation from a clear sky. On cloudy days when only diffused radiation is present at the top of the canopy, transmission is expected to be greater that of clear days. It is because that diffuse light of sky can't find many more holes to come through than can direct beam of sunlight (Trapp, 1938).

The availability of solar radiation (especially the PAR) has important implication for productivity of understorey grasses and other vegetation in a silvopastoral system. By using this knowledge, the potential of growing understorey pasture species in between the inter space of trees can be determined. The knowledge on special and temporal variation in PAR availability can be

effectively used in designing and optimization of both understorey and overall yields (Anderson, 1964).

Temperature

Temperature is like water in its action upon plant in that it has more or less to do with nearly every function, but as a working condition and not as a material. All the chemical processes of metabolism and also many physical processes such as diffusion are dependent upon temperature and get accelerated by its increase upto an optimum (Weaver and Clements, 1986). As in light, there is a daily and annual fluctuation in temperature. The amount of heat received depends upon the angle of sun's rays and their consequent absorption. The actual temperatures at the surface of the earth are greatly modify by radiation, conduction and convection (Pearson, 1930).

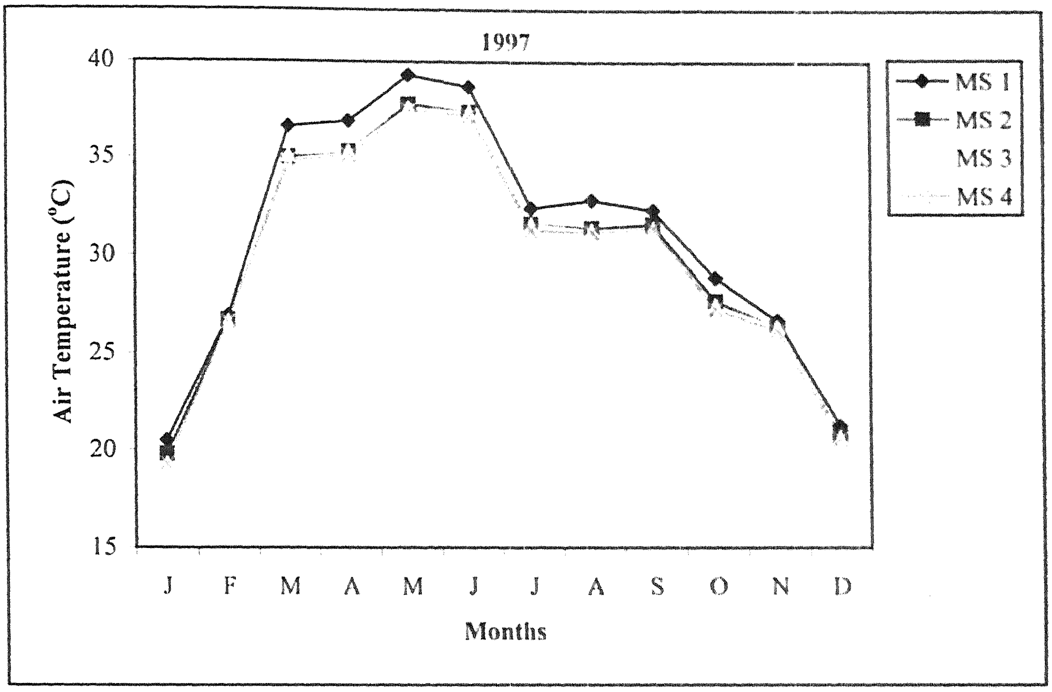
At a micro scale, temperature (air and soil) are affected by tree canopies (Corlett and Ong, 1989). The temperature of the plants tends to follow closely that of environment.

Air Temperature

The air temperature was found to be highest in open situation in both the years (Fig. 5). This could be primarily because of full radiation which maintained air temperature at a higher level. In silvopastoral systems, a decreasing level of air temperature was observed with the increase in tree density. In both the years, the critical difference in air temperature (annual average) between open and canopy situations was significant. However, the critical difference in different canopy situation was not significant in both the years (Table 4).

Soil Temperature

Soil temperature was found to be highest in open situation in both the years (Fig. 6). As in air temperature, this could be primarily because of full



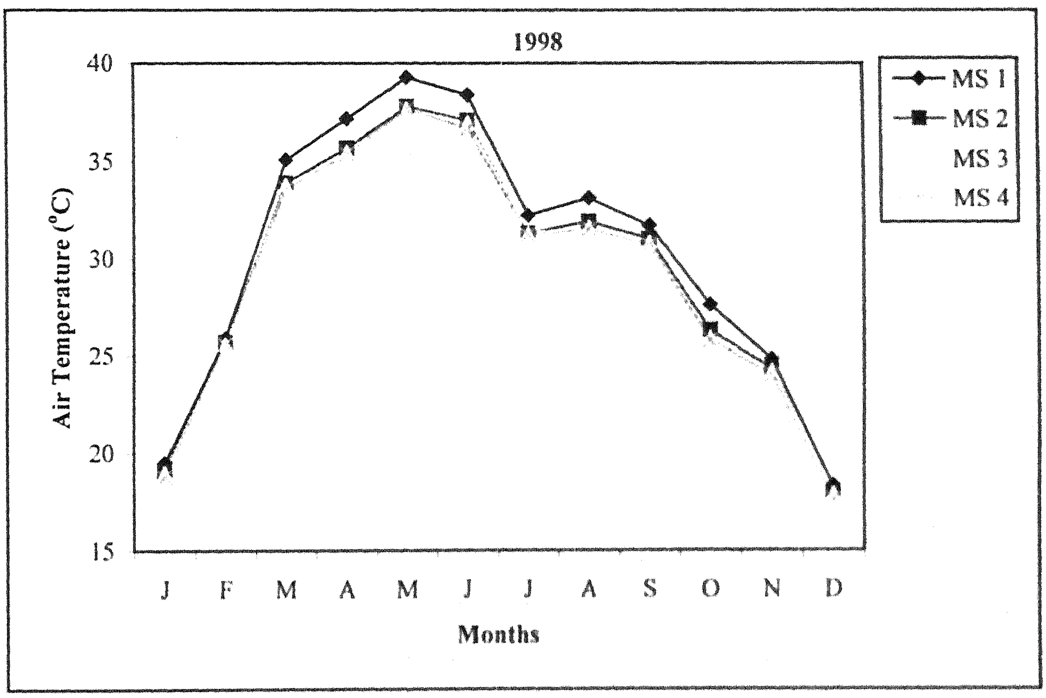
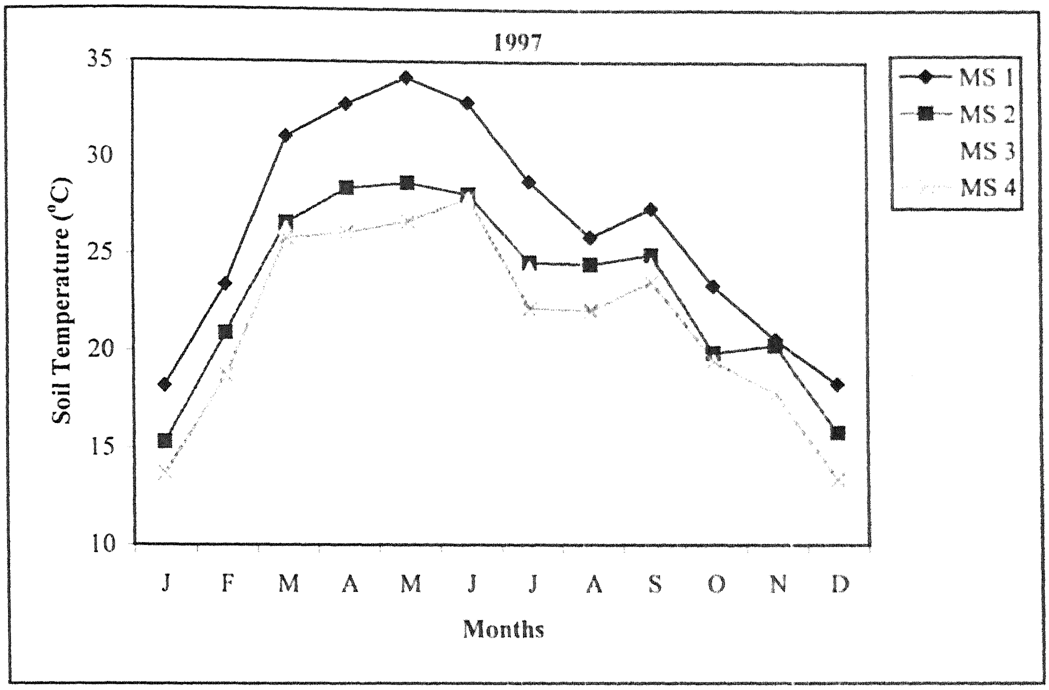


Fig. 5
Pattern of air temperature at the four microsites of the study (January-December).



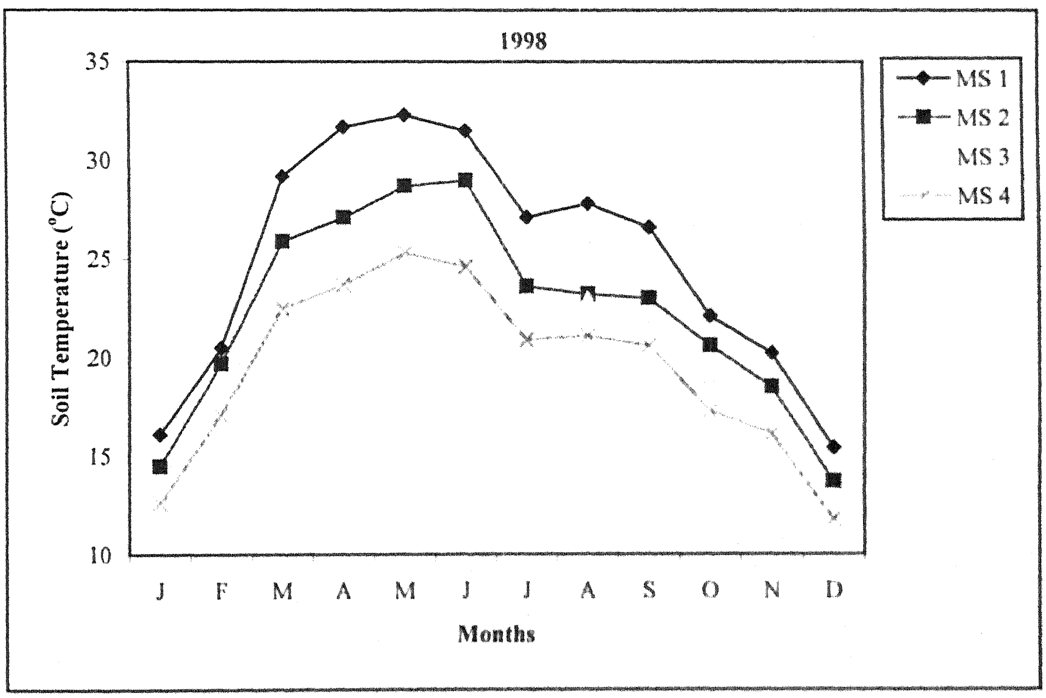


Fig. 6
Pattern of soil temperature at the four microsites of the study (January-December).

radiation which maintained soil temperature at a higher level. Similarly, in silvopastoral systems, a decreasing level of soil temperature was observed with the increase in tree density. In both the years, the critical difference in soil temperature (annual average) between open and canopy situations was significant. However, unlike the air temperature, the critical difference in different canopy situation was significant during 1998. In 1997 the differences were significant only between the light and medium canopy situations (Table 5).

Table 4
Air temperature under open and different canopy situations of *Albizia amara* (annual average) (in °C).

Canopy	1997	1998
Open	31.1±6.4	30.3±7.0
Light	30.1±6.0	29.3±6.7
Medium	30.0±6.0	29.2±6.6
Dense	30.0±6.0	29.0±6.7
	0.4	0.5

Table 5
Soil temperature under open and different canopy situations of *Albizia amara* (annual average) (in °C).

Canopy	1997	1998
Open	26.4±5.7	25.0±6.0
Light	23.2±4.7	22.3±5.1
Medium	22.2±5.1	20.7±4.6
Dense	21.5±4.9	19.5±4.5
	0.8	0.7

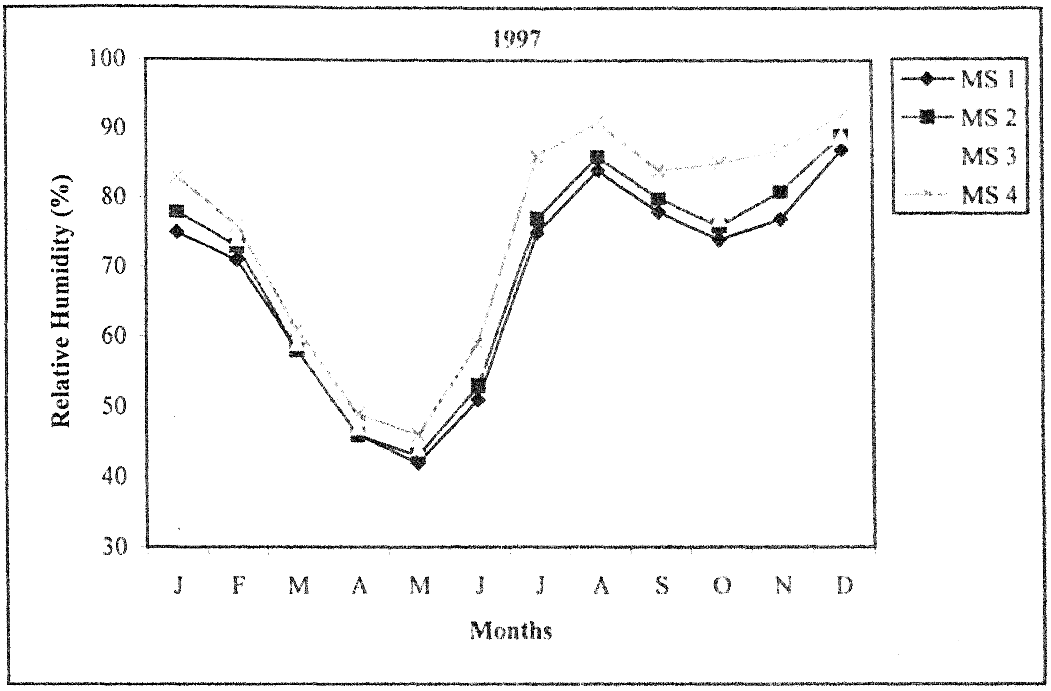
Similar trends in air/soil temperature under tree canopies have been reported by various workers. For instance Hazra and Tripathi (1986) observed lower temperature regime under grown up canopies of *Albizia lebbek, Acacia nilotica* and *Leucaena leucocephala*. Misra and Bhatt (1992) have also reported similar trends under the growing tree canopies of *Acacia tortilis, Hardwickia binata, Leucaena leucocephala, Albizia lebbek* and *Albizia amara*. Thus it would be seen that air/soil temperature is closely linked with the radiation availability at different microsites.

Relative Humidity (RH)

Humidity is one of the most important factor since it directly affect the rate of transpiration. The relative humidity (RH) is the ratio, expressed at per centage, of the water vapour actually present in the air (unit of space) at a certain temperature to the amount necessary to saturate the same unit of space under similar condition. Humidity is affected by a number of factors *viz.*, wind, altitude, exposure, vegetation cover and soil moisture (Mitchell, 1936).

The RH was found to be highest in the dense canopy situation in both the years (Fig. 7). Lowest range of RH was observed in open situation. This could be primarily because of lower radiation levels received under the tree canopies. In silvopastoral systems, an increasing level of RH was observed with the increase in tree density. In both the years, the critical difference in RH (annual average) between open and the dense canopy situation was significant. However, during 1998, the critical difference between open and medium canopy situation was also significant (Table 6).

Higher RH under tree cover has been reported by several workers. Ramakrishna and Sastri (1977) reported higher RH under mature *Acacia tortilis* trees in Rajasthan. Hazra and Tripathi (1986) reported higher RH under tree canopies *viz., Leucaena leucocephala* (80 %), *Acacia tortilis* (75 %) and



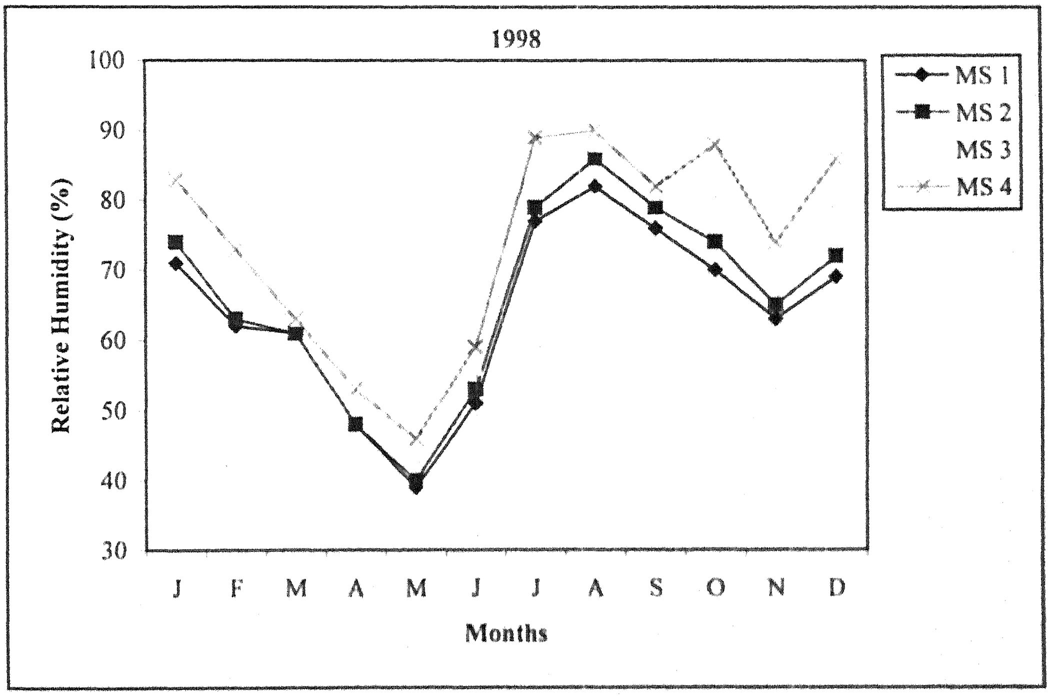


Fig. 7
Pattern of relative humidity at the four microsites of the study (January-December).

Hardwickia binata (55 %) as compared to open situation (50 %). Similarly, Hazra and Patil (1986) observed more RH (62-70 %) under medium sized trees of *Albizia lebbek, Albizia procera, Leucaena leucocephala* and *Acacia tortilis* as compared to open situation. Gill and Abrol (1987) reported higher RH below trees of *Prosopis juliflora* on salt affected soils in Haryana. The higher RH under tree cover was linked to lower radiation availability and more favourable soil moisture regime. In the present study the pattern of RH under different canopy density is correlated with radiation/soil moisture.

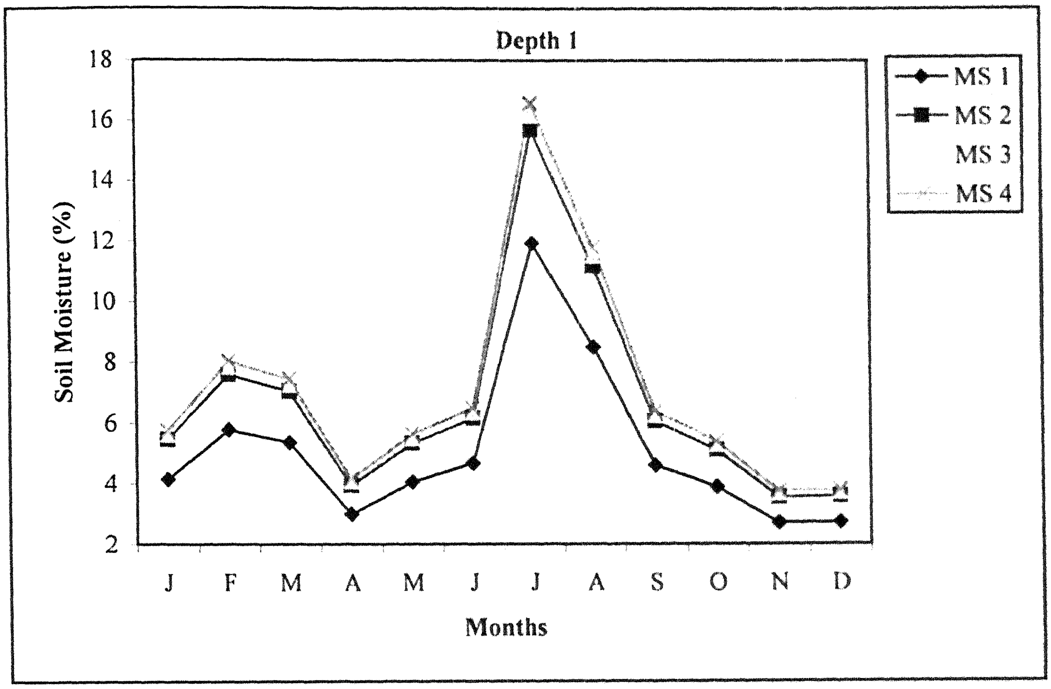
Table 6
Relative humidity under open and different canopy situations of *Albizia amara* (annual average) (%).

Canopy	1997	1998
Open	68±15	64±13
Light	70±16	66±14
Medium	72±16	70±14
Dense	75±17	74±16
	6	5

Soil Moisture

The soil moisture is vital to plant growth not only because plants need water for their physiological processes but also because the water contains nutrients in solution. The pattern of soil moisture availability in different months at two depth (0-15 cm, 15-40 cm) during 1997 and 1998 are presented in Figs 8 and 9.

It is evident from the figures that soil moisture varied in different months at all the four microsites. During June to November the moisture availability was



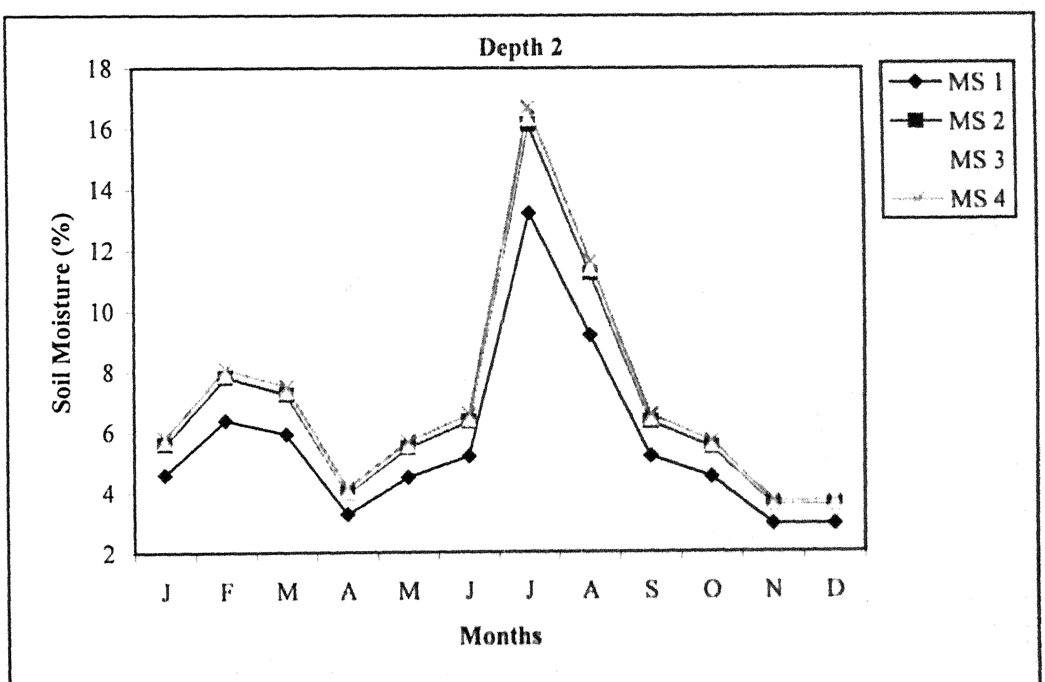


Fig. 8
Pattern of soil moisture availability at the four microsites of the study during 1997.

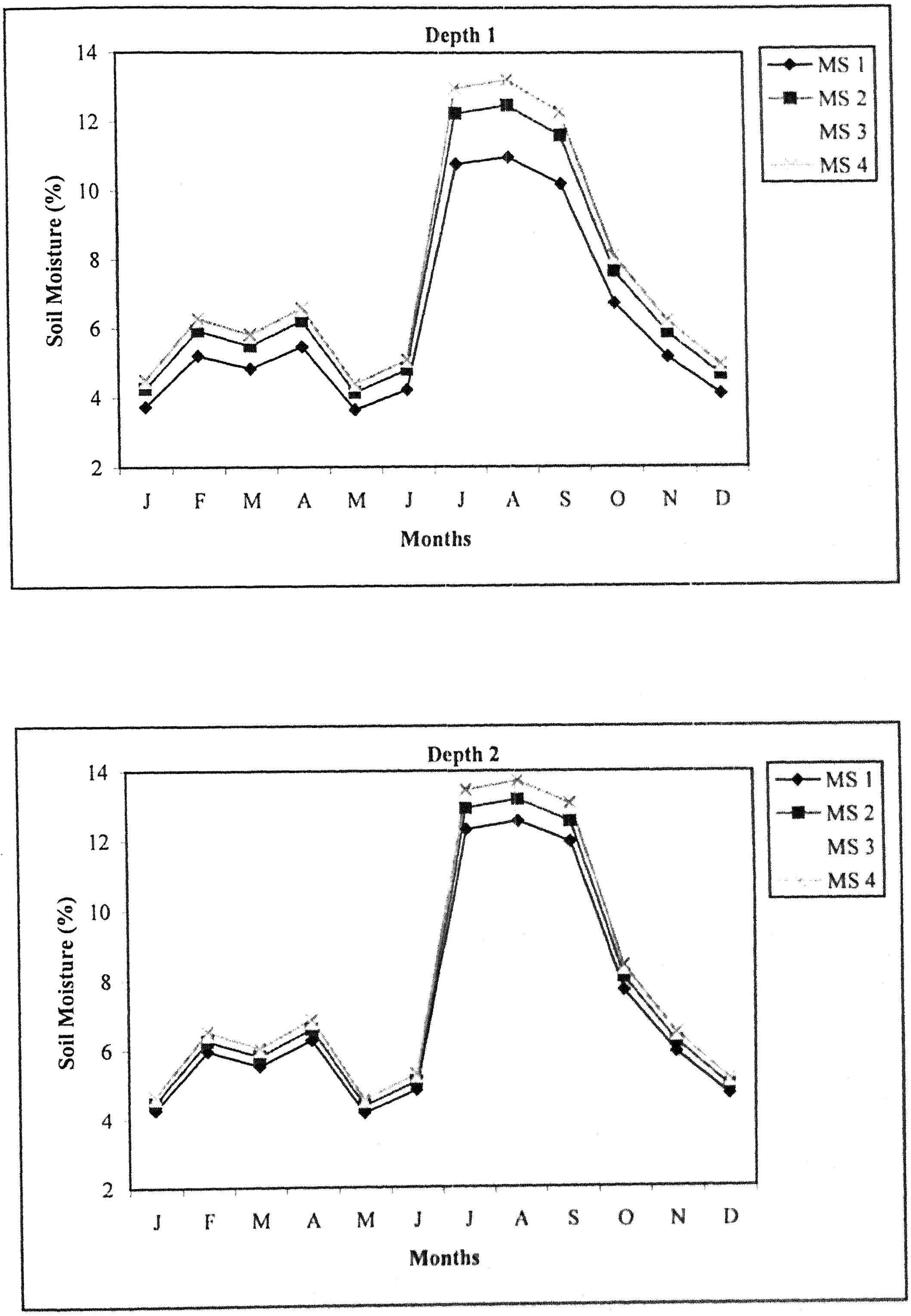


Fig. 9
Pattern of soil moisture availability at the four microsites of the study during 1998.

quite high as compare to the period during December to May. This may be attributed to the rainfall and evaporation pattern during the study period. The period June to November received over 87 per cent of total rainfall receipt. In a particular month, generally, more soil moisture was recorded under trees when compare to only pasture situation. Similarly, in silvopastures, a general increasing trend in soil moisture was found with increase in tree density.

Pattern of mean annual soil moisture in different depth at the four microsites is presented in Table 7. In both the years, the critical difference in mean soil moisture (annual average) between open and canopy situations was significant at both the depths. In silvopastoral systems, the differences were not significant at depth 1 (0-15 cm). However, significant difference was observed in between light and dense canopy situation at depth 2 (15-40 cm) (Table 7).

Table 7
Mean annual soil moisture (%) under tree canopies of *Albizia amara* (1997-1998).

	Depth		
Canopy	D1	D2	Mean
Open	5.69	6.41	6.05
Light	6.92	7.17	7.04
Medium	7.20	7.36	7.28
Dense	7.32	7.49	7.40
CD (P< 0.05)	0.46	0.32	

Soil moisture content has been linked to density of natural vegetation cover (Cunnigham, 1963) and type of clay/organic matter present in the soil (Thompson and Troch, 1985). Higher soil moisture regime under trees and its increase with the depth may be attributed to these reasons.

PART II

PLANT GROWTH

Pasture Growth

Botanical Composition of Herbage

In terrestrial ecosystems (like silvopasture) vegetation constitute the second major component after land, people and cattle. In such ecosystem the herbaceous layer and non leguminous part of woody shrubs and trees contribute towards fodder. The young and green succulent shoots of grasses and forbs of leguminosae provide the best choice for grazing material (Pandeya, 1988). The ground flora exhibit population fluxes due to succession. The botanical composition also keeps on changing because of external forces of harvesting, grazing, trampling, burning, lopping, browsing, shifting cultivation and timber removal (Singh and Misra, 1969). Thus studies on botanical composition of ground flora in silvopastures are of great significance for proper management and utilization of pasture component.

The botanical composition of ground vegetation at different microsites has shown that it could be grouped into grasses (both perennial and annual), legumes and weeds (Table 8). The number of perennial grasses was same in all the microsites. These were *Chrysopogon fulvus, Cenchrus ciliaris, Heteropogon contortus, Sehima nervosum and Dicanthium annulatum*. Also there was no appreciable difference in number of annual grasses, legumes and weeds in different microsites.

Immediately after the first monsoon showers, the seedlings of annual and perennial grasses started sprouting and were followed by vigorous vegetation growth. Flowering started in the beginning of August/September which continued into October. Fruiting was followed immediately after flowering. The rainy season annuals and shoots of many perennial species dried up in late October/early November and many remained as dead biomass until battered down as litter by wind. Decomposition of litter was hastened by winter showers. The

Table 8.
List of species observed at the study site (1997-1998).

Plant Species	Microsites			
	MS 1	MS 2	MS 3	MS 4
Perennial Grasses				
Cenchrus ciliaris Linn.	+	+	+	+
Chrysopogon fulvus (Spreng) Chiv.	+	+	+	+
Dicanthium annulatum (Forsk.) Stapf.	+	+	+	+
Heteropogon contortus (L.) Beauv. ex. Roem. & Schult.	+	+	+	+
Sehima nervosum (Willd.) Stapf.	+	+	+	+
Annual Grasses				
Apluda mutica L.	+	+	+	+
Aristida adscensionis L.	-	+	+	+
Brachiaria mutica (Forsk.) Stapf.	+	+	+	+
Brachiaria ramosa (L.) Stapf.	-	-	+	+
Digitaria ciliaris (Retz.) Koel.	+	+	-	+
D. sanguinalis (L.) Scop.	-	+	-	-
Dactyloctenium aegyptium (L.) Willd.	+	-	+	+
Eragrostis pilosa (L.) P. Beauv.	+	+	-	+
Eragrostis tenella (L.) P. Beauv. ex. R.& S.	-	+	-	+
Echinochloa colona (L.) Link	-	+	+	-
E. crusgalli (L.) P. Beauv.	-	-	+	-
Eleusine indica (L.) Gaertn.	+	-	+	-
Polypogon monspeliensis (L.) Desf.	+	-	-	+
Setaria glauca P. Beauv.	+	+	+	+
Setaria intermedia R.& S.	+	+	-	+
Themeda quadrivalvis (L.) O. Ktze.	+	+	+	+
Legumes				
Alysicarpus monilifer (L.) DC.	+	+	+	+
Alysicarpus vaginalis (L.) DC.	-	+	-	+
Atylosia scarabaeoides (L.) Benth.	-	+	-	-
Goniogyna hirta (Willd.) Ali	+	-	+	+
Indigofera astragalina DC.	+	+	-	-
I. linifolia (L.f.) Retz.	-	-	+	-
I. linnaei Ali	-	-	+	+
Lathyrus apacha L.	+	+	+	+
Rhynchosia minima (L.) DC.	+	+	+	+
Senna tora (L.) Roxb.	+	+	+	+
Tephrosia purpurea (L.) Pers.	-	+	+	+
Tephrosia villosa (L.) Pers.	+	-	+	+
Vicia sativa L.	+	+	-	+
Vigna aconitifolia (Jacq.) Marechal	+	-	-	+

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Weeds				
Achyranthes aspera L.	+	+	+	+
Ageratum conyzoides L.	+	+	+	+
Blainvillea acmella (L.) Philipson	-	+	+	-
Boerhavia diffusa L.	+	+	+	+
Borreria hispida (L.) F. N. Will.	-	+	-	+
Borreria pusilla (Wall.) DC.	-	+	+	-
Celosia argentea L.	+	+	-	+
Cleome viscosa L.	+	-	+	+
Cocculus hirsutus (L.) Diels.	+	+	+	+
Commelina benghalensis L.	+	-	+	-
Convolvulus microphyllus Sieb. ex. Spreng.	+	+	-	+
Corchorus aestuans L.	+	-	+	+
Cynoglossum denticulatum (L.) DC.	+	-	-	+
Cyperus rotundus L.	+	+	+	+
Cyperus triceps (Rotth.) Endl.	-	+	+	-
Eclipta prostrata (L.) L.	-	-	+	+
Enicostema axillare (Lamk.) Roynal	+	-	-	+
Euphorbia hirta L.	+	+	+	+
Evolvulus alsinoides (L.) L.	+	+	+	-
Gnaphalium purpureum L.	+	+	+	-
Justicia diffusa Willd.	+	+	+	-
Lantana camara L.	+	+	-	+
Launaea asplenifolia (Willd.) Hook. f.	+	+	+	-
Leucas aspera (Willd.) Spreng.	+	-	+	+
Oldenlandia corymbosa L.	+	+	-	+
Parthenium hysterophorous L.	+	+	+	+
Phyllanthus fraternus Webster	+	+	+	+
Portulaca oleracea L.	+	+	+	-
Sida cordifolia L.	+	+	+	+
Sida acuta Burm. f.	-	+	-	+
Trichodesma indicum (L.) R. Br.	+	+	+	-
Tridax procumbens L.	+	+	+	+
Urena lobata L.	+	-	-	+
Vernonia cinerea (L.) Less.	+	+	-	-
Vicoa indica (L.) DC.	+	+	+	+

(+ = Present; - = Absent)

winter season annual germinated by this time and there was tillering of perennial grasses. The phenological pattern observed on this site coincides well with other monsoonic grassland/grazing land in India (Singh and Yadav, 1974).

Table 9 presents the data on mean herbage composition at different microsites. It is evident from the table that total density of ground vegetation was higher in open situation when compared to the canopy situation. The share of perennial and annual grasses decreased markedly under dense canopy situation. However, share of legumes and weeds increased in the canopy situations.

Singh *et al.* (1985) have studied botanical composition of herbage under *Pinus roxburghii* plantation in Himachal Pradesh. They found higher density of herbage in open situation as compared to canopy situation. Similarly, floristic composition of herbaceous vegetation under *Quercus incana, Cedrus deodara* and *Pinus roxburghii* was studied by Singh and Verma (1986) in Himachal Pradesh. They also found similar results. The botanical composition of herbage under tree canopy of *Leucaena leucocephala* and *Acacia tortilis* has been studied at Jhansi (Singh *et al.*, 1990). A decrease in share of perennial grasses under trees was reported, higher decrease being noticed under *Leucaena leucocephala*. The total density was also reported to be higher under open situation.

Vigour of Perennial Grasses

Aboveground

After stand structure, plant vigour of prominent perennial grass species is an important attribute of grassland/silvopasture. It indicates the role of species in forage production and management. Several workers have studied effects of certain practices like grazing (Hazella, 1967), defoliation (Deb Roy *et al.*, 1975) and nutrient application (Shankarnarayan *et al.*, 1975; 1976) on grass vigour in some grasslands of India. Vigour attributes *viz.*, plant height, tussock diameter, number of tiller/tussock for all the five perennial grasses were studied at the four microsites. These are being discussed as under.

Table 9
Mean herbage composition at different microsites (1997-1998).

Attributes	Microsite			
	MS 1	MS 2	MS 3	MS 4
Number of plants (/m^2)				
(i) Perennial grasses	5	3	3	2
(ii) Annual grasses	3	3	3	3
(iii) Legume forbs	5	3	3	4
(iv) Weeds	6	7	8	9
Total density (no/m^2)	417	322	287	229
Density shared by (%)				
(i) Perennial grasses	80.8	72.2	63.5	66.9
(ii) Annual grasses	7.6	6.9	6.3	2.8
(iii) Legume forbs	4.1	7.8	7.8	7.9
(iv) Weeds	7.5	13.1	22.4	22.4

Plant Height

The average height, tussock diameter and number of tillers at different microsites is presented in Fig. 10. Average grass height varied from 40.0 to 62.4 cm. More height was recorded in open situation when compared to canopy situation. In silvopastures, a consistent trend of decrease in height was observed under silvopastures with increase in tree density.

Table 10 presents data on average growth characteristics of individual grasses in different microsites of study. At microsite 1, peak average height was exhibited by *Chrysopogon fulvus* (77.1 cm) followed by *Cenchrus ciliaris* (67.9 cm), *Heteropogon contortus* (60.5 cm), *Sehima nervosum* (55.2 cm) and *Dicanthium annulatum* (55.1 cm). At microsite 2, peak average height was exhibited by *Chrysopogon fulvus* (54.5 cm) followed by *Heteropogon contortus* (51.3 cm), *Sehima nervosum* (51.2 cm), *Dicanthium annulatum* (43.9 cm) and *Cenchrus ciliaris* (39.6 cm). At microsite 3, peak average height was exhibited by *Heteropogon contortus* (47.6 cm) followed by *Sehima nervosum* (46.1 cm), *Chrysopogon fulvus* (42.4 cm), *Dicanthium annulatum* (41.2 cm) and *Cenchrus ciliaris* (34.2 cm). At microsite 4, peak average height was exhibited by *Sehima nervosum* (44.2 cm) followed by *Heteropogon contortus* (43.7 cm), *Chrysopogon fulvus* (40.1 cm), *Dicanthium annulatum* (39.8 cm) and *Cenchrus ciliaris* (32.6 cm).

The height growth showed a decreasing trend with increase in canopy density. Such differences between the microsites could be because of the varying microclimatic conditions prevailing on these sites. Similar differences in grass vigour has been reported by several workers in arid and semi arid conditions (Gupta and Saxena, 1972; Kanodia, 1981; Trivedi and Gupta, 1994).

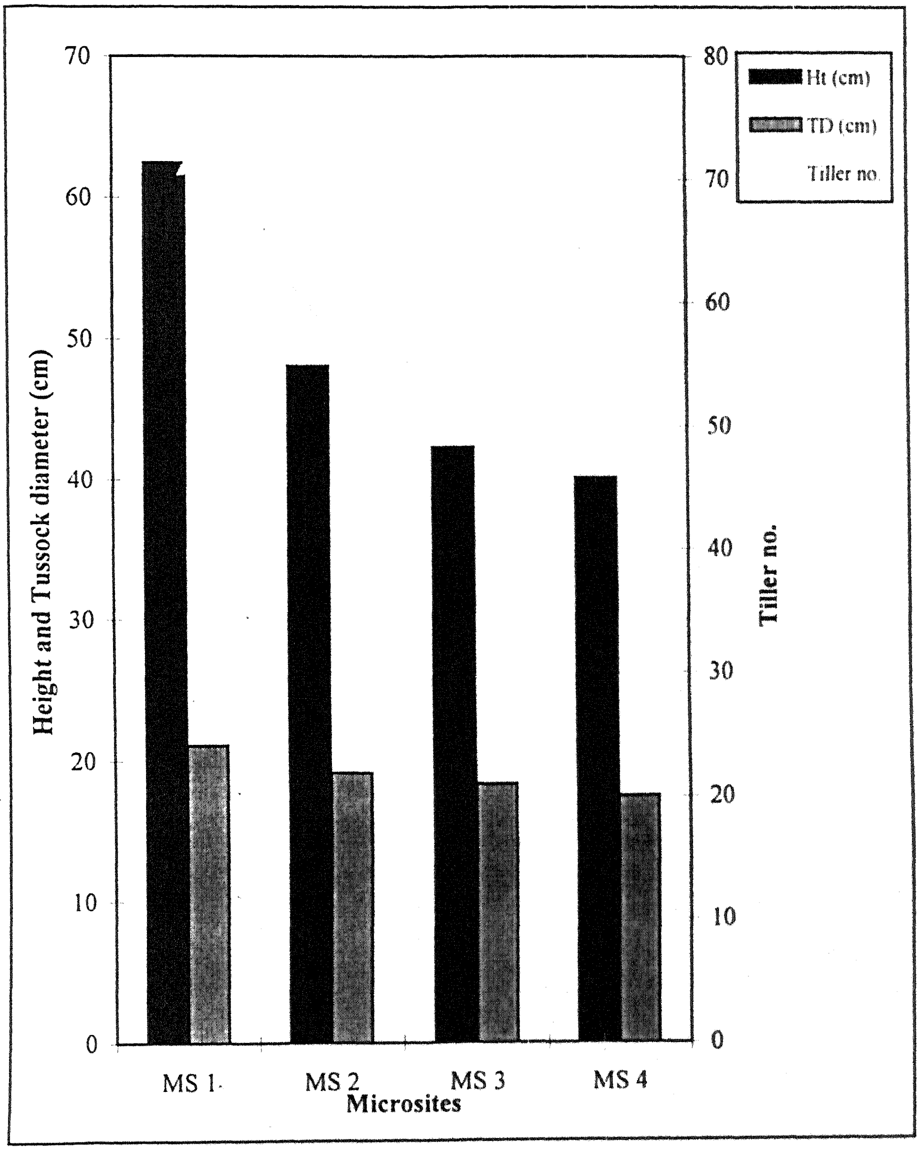


Fig. 10
Average pasture growth characteristics at the four microsite of study (1997-1998).

Table 10
Average growth characteristics of individual grasses in different microsites of study.

Microsite	Growth characteristics	Grass species				
		(1)	(2)	(3)	(4)	(5)
MS 1	Height (cm)	77.1	67.9	60.5	55.2	51.5
	Tussock diameter (cm)	23.5	22.8	24.6	19.3	15.4
	Tiller No.	95	87	79	51	43
MS 2	Height (cm)	54.5	39.6	51.3	51.2	43.9
	Tussock diameter (cm)	21.7	21.7	23.7	17.1	11.7
	Tiller No.	77	76	63	42	30
MS 3	Height (cm)	42.4	34.2	47.6	46.1	41.2
	Tussock diameter (cm)	20.6	21.1	22.6	16.5	11.1
	Tiller No.	73	71	57	38	26
MS 4	Height (cm)	40.1	32.6	43.7	44.2	39.8
	Tussock diameter (cm)	20.6	20.4	22.1	14.3	10.4
	Tiller No.	63	63	51	37	22

1-*Chrysopogon fulvus*, 2-*Cenchrus ciliaris*, 3-*Heteropogon contortus*, 4-*Sehima nervosum*, 5-*Dicanthium annulatum*

Tussock Diameter

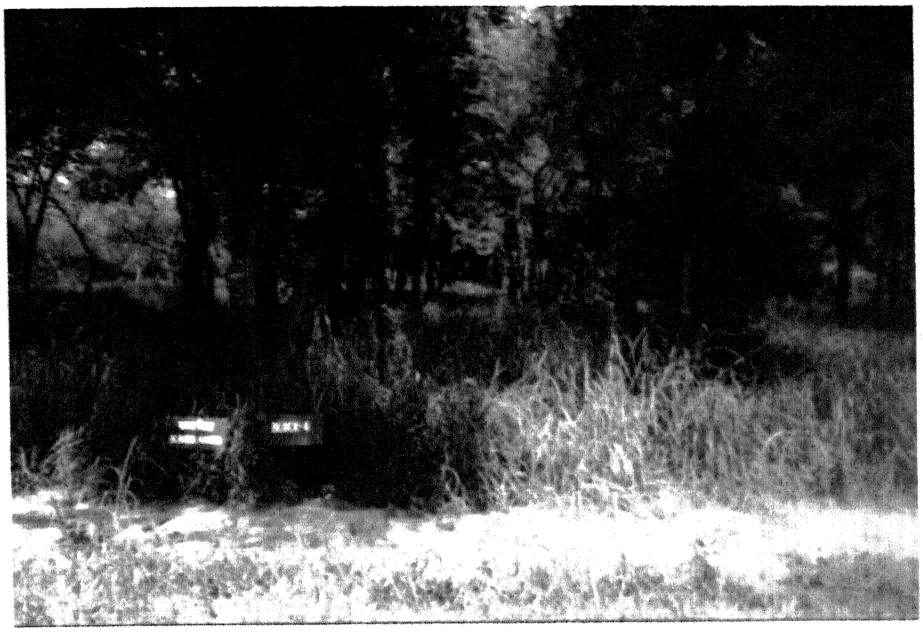
At microsite 1, peak average tussock diameter was exhibited by *Heteropogon contortus* (24.6 cm) followed by *Chrysopogon fulvus* (23.5 cm), *Cenchrus ciliaris* (22.8 cm), *Sehima nervosum* (19.3 cm) and *Dicanthium annulatum* (15.4 cm). At microsite 2, peak average tussock diameter was exhibited by *Heteropogon contortus* (23.7 cm) followed by *Chrysopogon fulvus/Cenchrus ciliaris* (21.7 cm), *Sehima nervosum* (17.1 cm) and *Dicanthium annulatum* (11.7 cm). At microsite 3, peak average tussock diameter was exhibited by *Heteropogon contortus* (22.6 cm) followed by *Cenchrus ciliaris* (21.1 cm), *Chrysopogon fulvus* (20.6 cm), *Sehima nervosum* (16.5 cm) and *Dicanthium annulatum* (11.1 cm). At microsite 4, peak average tussock diameter was exhibited by *Heteropogon contortus* (22.1 cm) followed by *Chrysopogon fulvus* (20.6 cm), *Cenchrus ciliaris* (20.4 cm), *Sehima nervosum* (14.3 cm) and *Dicanthium annulatum* (10.4 cm).

The growth in tussock diameter showed a decreasing trend with increase in canopy density. Such differences between the microsites could be because of the varying microclimatic conditions prevailing on these sites. Similar difference in grass vigour has been reported in some temperate (Smith *et al.*, 1971) and tropical (Trivedi and Gupta, 1994) conditions.

Tiller Number

At microsite 1 highest average tiller number was exhibited by *Chrysopogon fulvus* (95) followed by *Cenchrus ciliaris* (87), *Heteropogon contortus* (79), *Sehima nervosum* (51) and *Dicanthium annulatum* (43). At microsite 2 highest average tiller number was exhibited by *Chrysopogon fulvus* (77) followed by *Cenchrus ciliaris* (76), *Heteropogon contortus* (63), *Sehima nervosum* (42) and *Dicanthium annulatum* (30). At microsite 3 highest average tiller number was exhibited by *Chrysopogon fulvus* (73) followed by *Cenchrus ciliaris* (71), *Heteropogon contortus* (57), *Sehima nervosum* (38) and *Dicanthium*

Plate 2



Pasture growth under a dense stand of *Albizia amara*

A view of the *Albizia amara* stand after grass harvest during dry season (in right)

annulatum (26). At microsite 4 highest average tiller number was exhibited by *Chrysopogon fulvus/Cenchrus ciliaris* (63) followed by *Heteropogon contortus* (51), *Sehima nervosum* (37) and *Dicanthium annulatum* (22).

The trend in tiller number suggest that microclimatic condition and nutrient status have influence in determining the tillering behaviour of different species. Similar results have been reported by several workers (Gupta and Saxena, 1972; Pathak and Rai, 1990).

Belowground

In silvopastoral systems, distribution of grass roots play an important structural role in stablising soil. It is also important from the viewpoint of resource sharing (soil, moisture and nutrients).

The root growth characteristics of the five perennial grasses at the study site are presented in Table 11. Maximum depth of root penetration in soil, mean length of root and mean thickness of root was found in *Chrysopogon fulvus* (35.8 cm, 29.6 cm, 0.74 mm). The root penetration in soil was followed by *Cenchrus ciliaris* (32.4 cm), *Heteropogon contortus* (29.2 cm), *Sehima nervosum* (22.1 cm) and *Dicanthium annulatum* (17.6 cm). The average length and thickness of root was followed by *Heteropogon contortus* (23.8 cm, 0.51 mm), *Cenchrus ciliaris* (22.5 cm, 0.46 mm), *Sehima nervosum* (17.3 cm, 0.39 mm) and *Dicanthium annulatum* (11.0 cm, 0.24 mm). The mean number of root per plant was recorded in *Cenchrus ciliaris* (527/tussock) followed by *Chrysopogon fulvus* (382/tussock), *Heteropogon contortus* (315/tussock), *Sehima nervosum* (187/tussock) and *Dicanthium annulatum* (89/tussock).

The pattern of root depth and root spread, exhibited by a species mixture on a site, have important ecological implication. Deep rooted species may on one hand be preferred the stablising the soil, the comparatively shallow rooted species with more spread may be desirable for maximum utilization of water (Hellemers *et al.*, 1955).

Table 11
Root growth characteristics of five perennial grasses at the study site.

Species	Mean tussock diameter (cm)	Maximum depth of root penetration in soil (cm)	Mean no. of roots /plant	Mean root length (cm)	Mean root thickness (mm)
C. fulvus	22.6	35.8	382	29.6	0.74
C. ciliaris	21.5	32.4	527	22.5	0.46
H. contortus	20.3	29.2	315	23.8	0.51
S. nervosum	16.8	22.1	187	17.3	0.39
D. annulatum	12.1	17.6	89	11.0	0.24

Bist and Kediyal (1989) have studied the root growth characteristics of some grasses in temperate region of Garhwal. Based on root characteristics they concluded that a mixed plantation of *Chrysopogon citrarus* and *Agrostis stolonifera* to be useful from soil conservation viewpoint in this region. In this study higher vigour in root growth has been exhibited by *Chrysopogon fulvus*, *Cenchrus ciliaris* and *Heteropogon contortus* when compared to *Sehima nervosum* and *Dicanthium annulatum*.

Tree Growth

Phenology

Phenology is the study of growth of buds, leaf fall, anthesis, fruiting and seed dispersal in relation to months, seasons or years. These are governed by climatic factors like photoperiod, temperature, moisture and precipitation etc. The phenological study of the ecosystem can help to layout management practices for

a balanced ecosystem function (Leith, 1970). Such studies may also be important from seed collection viewpoint (Mahadevan, 1991).

The period of different phenophase of *Albizia amara* at the study site is represented in Table 12. The leaf fall was more evident March onwords and continued up to June. This appears to be a sort of xerophytic adaptation to protect itself from rigours of dry season. This character is also seen in some other deciduous species like *Tamarix articulata, Phyllanthus emblica* and *Casuarina equisetifolia* (Mac Dicken, 1994).

Flushing and leaf formation occurred in April-May. However, leaf formation continued up to September. The leaf replacement strategies during summer months appears to minimize stress by leaf fall at such period and maximize photosynthetic activity during wet warm season of the year through flushing (Njoku, 1963; Shukla and Ramakrishnan, 1982).

The buds and flowers appeared in April and continued up to May. Pods developed rapidly and reached to full size by June end.

Aboveground

The growth attained by trees is an important attribute of silvopastoral system as it is an indication of its role in supplying timber, firewood and fodder etc. besides determining the optimum rotation period of the system. Similarly, canopy spread has significant implications in determining the microclimate beneath it which in turn may affect the productivity of understorey species (Deb Roy, 1988 a; 1988 b; Singh *et al.*, 1992; 1993; 1994).

The growth of *Albizia amara* was studied at the three silvopastures microsites. The results are being presented in Tables 13 and 14.

Height

There was not much difference in average height of trees at different microsites. Hence mean annual increment also remained same at the different

Table 12
Period of different phenophases of *Albizia amara* at the study site. (values are on a scale of 1-10) (average 1997-1998).

Phenophase	Months	Scale
Leaf fall	March	7.5
	April	8.5
	May	9.8
	June	10.0
Leaf flushing & Leaf formation	April	1.6
	May	2.7
	June	3.6
	July	8.0
	August	8.4
	September	9.4
Budding & Flowering	April	2.0
	May	10.0
	June	-
Fruiting	March	-
	April	-
	May	3.1
	June	10.0

Table 13
Mean annual increment in growth parameters of *Albizia amara* in silvopastoral systems (at 25th year).

Microsite	Height (m)	Canopy (m)	cd (cm)	dbh (cm)
MS 2	0.36	0.11	1.63	1.15
MS 3	0.36	0.10	1.36	1.00
MS 4	0.36	0.09	1.27	0.88
CD (>0.05)	NS	NS	0.14	0.19

Table 14
Average growth characteristics of *Albizia amara* (1997-1998).

Microsite	Height	Canopy	cd (cm)	dbh (cm)
MS 2	9.00	2.75	40.75	28.75
MS 3	9.00	2.50	34.00	25.00
MS 4	9.00	2.25	31.75	22.00

microsites. It shows that these trees have attained a plateau in height growth by this time and further rate of increase is extremely slow. Similar trend of height growth in respect of several forest trees has been reported by Troup (1921).

Canopy Spread

The average spread in canopy decreased from 2.75 m at microsite 2 to 2.25 m at microsite 4. Hence mean annual increment also decreased from 0.11 to 0.09 m. However, the differences in between different microsites were not significant statistically.

The growth in canopy has been related with number of trees per ha, lesser number indicating higher growth. Such a trend has been reported from 20^{+} year old trees of *Acacia senegal, Albizia lebbek, Prosopis cineraria* and *Tecomella undulata* in arid conditions of Rajasthan (Muthana *et al.*, 1984).

Diameter

The average growth in diameter (cd/dbh) decreased from (40.8/28.8 to 31.8/22.0 cm). Hence mean annual increment in cd/dbh also decreased from 1.63/1.15 cm to 1:27/0.88 cm. The diameter decreased consistently with the increase in tree density. Thus, like canopy spread the growth in diameter was found related to the number of trees per ha. Similar trend of diameter growth from mature trees of *Acacia senegal, Albizia lebbek, Prosopis cineraria* and *Tecomella undulata* has been reported by Muthana *et al.* (1984)

Belowground

Root growth study in silvopastoral systems are of great significance to manage tree and grass component (Prajapati *et al.*, 1971; Dhyani *et al.*, 1990; Patil *et al.*, 1994).

The root growth characteristics of *Albizia amara* at the study site are presented in Table 15. The length of tap root varied from 1.1 to 1.6 m in different

trees of *Albizia amara*. The number of major secondary roots varied from 21 to 29. This compares well with the root system of similar aged trees of *Prosopis cineraria, Acacia senegal* and *Albizia lebbek* growing in arid regions of Rajasthan. This is based on the data reported by Muthana *et al.* (1984). The diameter of tap root varied from 26.3 to 34.7 cm, 10.7 to 16.4 cm and 0.80 to 2.3 cm at the base, center and tip zones, respectively. This indicates that bulk of roots are confined within 1 m of soil depth.

Table 15
Root growth characteristics of *Albizia amara* at the study site.

Growth characteristics	Range	Average
Tree height (m)	8.7 – 9.3	9.0
Tree dbh (cm)	21.2 – 29.8	25.5
Length of tap root (m)	1.1 – 1.6	1.3
Number of major secondary roots	21 – 29	27
Diameter of tap root (cm)		
Base	26.3 – 34.7	31.3
Centre	10.7 – 16.4	12.4
Tip	0.8 – 2.3	1.1

Dhyani *et al.* (1990) reported similar observation on several young tree species *viz.*, *Grewia optiva, Bauhinia purpurea, Eucalyptus tereticornis, Leucaena leucocephala* and *Ougeinia oojeinensis* in Doon vally. However, they did not notice any significant difference in soil moisture under tree canopy cover and in open. In this present study, soil moisture was found to be higher under trees as compared to open situation as a result of favourable microclimate under trees. Thus, *Albizia amara* appears to be a desirable tree for agroforestry/silvopastoral systems where tree and pasture can fed from different depth (Berendse, 1979).

PART III

SYSTEM PRODUCTIVITY

Assessmemt of system productivity in silvopastoral systems are of great significance for proper management and utilization of various products *viz.*, timber, firewood and fodder. The understorey, consisting of herbaceous species, constitutes the major source of fodder during July/August to November/December in semi-arid regions. The pasture species play a key role in any improvement and more intensive system of land utilization. According to Pandeya (1988) full use of pasture resources and conserving them to the region of negative feed back, alone, will lead to plan maintenance of homeostatic plateau for lasting economy.

Ground Vegetation

In this study, for the purpose of biomass estimation the ground vegetation was grouped into grasses (both perennial and annual) and leguminous forbs/weeds. Table 16 presents the data on understorey biomass production at different microsites during 1997 and 1998. Significantly higher level of aboveground biomass was recorded in open situation when compared to the canopy situations in both the years. During 1998 the production level was higher when compared to 1997. This may be attributed on account of two reasons; (i) higher rainfall receipts during 1998 and (ii) heavy lopping practiced on these stands during 1997. Among different canopy situations significant difference in aboveground yield was recorded in between light and dense canopy situation only. As expected highest reduction in aboveground biomass production was recorded in dense canopy situation (71.5 %) followed by medium canopy (60.4 %) and light canopy situation (54.3 %).

The proportion of leguminous forbs/weeds was higher under canopy situations (12.2 to 14.5 %) when compared to the open situation (10.4 %) (Table 16). Among canopy situations highest proportion of leguminous forbs/weeds was recorded in dense situation (14.5 %) followed by light situation (13.9 %) and

medium situation (12.2 %). This could be attributed to the interaction between modified microclimatic condition and edaphic condition prevailing at a particular microsite.

Like the aboveground biomass production, significantly higher level of belowground biomass production was recorded in open situation when compared to the canopy situations in both the years. During 1998 the production level was higher when compared to 1997. This may be attributed on account of higher rainfall receipt during 1998 and more opening of the canopy as a result of heavy lopping practiced on these stands during 1997. Among different canopy situations significant difference in below ground yield was recorded in between light and dense canopy situations only. Highest reduction in below ground biomass production was recorded in dense canopy situation (76.9 %) followed by medium canopy situation (71.1 %) and light canopy situation (66.9 %). The level of reduction under canopy situations was higher in case of below ground biomass when compared to the above ground biomass (Table 16).

The total biomass production from ground vegetation was calculated (Table 16). Significantly higher level of total biomass recorded in open situation when compared to the canopy situations in both the years. Consistently, higher level of total biomass production was maintained during 1998 when compared to 1997. The reasons for this have already been mentioned in the above paragraph. Among different canopy situation significance difference in total yield was observed between light and dense canopy during 1997. However, during 1998 the differences between light and medium/dense canopy were significant. Highest reduction in total yield was recorded in dense canopy situation (72.9 %) followed by medium canopy situation (63.2 %) and light canopy situation (57.6 %). The higher proportion of below ground biomass (25 %) was recorded in open situation when compared to the canopy situation (0.20-0.21 %).

The productivity of grasses is an important attribute of carrying capacity of rangelands as it has important implication in forage supply. The biomass in

Table 16
Understorey biomass production (DM t/ha) at different microsites (1997-1998).

Parameter	Year	Microsite MS 1	MS 2	MS 3	MS 4	CD (<0.05)
AG Biomass	1	3.37 (9.3)	1.34 (13.7)	1.16 (11.9)	0.89 (14.2)	0.33
	2	3.86 (11.5)	1.97 (14.2)	1.70 (12.6)	1.17 (14.8)	0.59
	Mean	3.61 (10.4)	1.65 (13.9)	1.43 (12.2)	1.03 (14.5)	--
BG Biomass	1	1.16	0.31	0.28	0.24	0.06
	2	1.27	0.49	0.43	0.32	0.12
	Mean	1.21	0.40	0.35	0.28	--
Total Biomass	1	4.53	1.65	1.44	1.13	0.38
	2	5.13	2.46	2.13	1.49	0.61
	Mean	4.83	2.05	1.78	1.31	--

(NOTE: Value in parenthesis indicate percent biomass on dry matter basis contributed by the weeds)

grasses is more concentrated at base giving the appearance of an upright pyramid, the extent of which depends on the height of plants (Singh and Yadav, 1974). The layer structure of a multi layer pasture community has several advantages. For example, each quantum of incident light has great probability of being intercepted and used in a multi layered canopy as compared to single layer canopy (Pandeya, 1974). Such an arrangement has important implication in prolonging forage availability (Singh, 1968).

Although, density of individual species is a good expression of their relative abundance, it is a not related with the biomass often of the species. However, total vegetation density (number of tiller/m^2) of grazing lands has been found to be possitively correlated with total community aboveground biomass (Singh and Yadav, 1972). In this study, the yield of at different microsites was found to be related with total density of ground vegetation. For example, highest plant density in open situation (417/m^2) is related with peak average above ground biomass production (3.61 DM t/ha). Also, density shared by perennial grasses was higher in open situation (80.8 %) when compared to the canopy situation (63.5-72.2 %). These growth attributes are infact reflected in their biomass contribution.

Similar results have been obtained by Mall and Billore (1974) between vegetation density and net aerial primary production for a *Sehima* grazing land near Ratlam in Central India. Singh (1990) found relationship between plant stand, ground cover and dry matter production in some promising grasses *viz.*, *Pennisetum purpureum, P. purpureum - P. typhoides* - IGFRI 5 and *Panicum maxicum* cultivar Cv Makueni. Kateva and Tiagi (1991) reported similar results from three grazing lands of Udaipur District each dominated by an important grasses species *viz.*, *Sehima nervosum, Heteropogon contortus* and *Apluda mutica*. In Central Himalaya, species composition and density determined herbage yield at different sites under *pine* forest (Chaturvedi and Saxena, 1992).

Grass productivity under silvopastoral systems has been studied by several workers. Ramakrishna *et al.* (1981) reported poor yield of *Cenchrus ciliaris* under

mature and unlopped trees of *Acacia tortilis* as compared to open situation at Jodhpur. The low energy availability beneath the canopy was identified as the cause for poor performance of *Cenchrus ciliaris*. However, Deb Roy *et al.* (1980) found marginal difference in forage production of *Cenchrus ciliaris* and *Cenchrus setigerus* grown an association with medium sized *Acacia tortilis/Leucaena leucocephala* trees when compared to open situation at Jhansi.

Hazra and Patil (1986) reported forage yield of grasses under different moderate sized trees *viz.*, *Albizia lebbek, Albizia procera, Leucaena leucocephala* and *Acacia tortilis* and in open situation at Jhansi. Dry forage yield marginally decreased under *Acacia tortilis* (7.9 %), *Leucaena leucocephala* (14.4 %) and *Albizia procera* (6.0 %) canopies. They identified microclimatic variation as the main reason for such a difference. Deb Roy (1988) reported higher forage production from a mixture of *Sehima nervosum* + *Chrysopogon fulvus* (3.76 DM t/ha) compared to that of *Cenchrus ciliaris* alone (3.30 DM t/ha) under moderate canopy of *Hardwickia binata*. The production level from the same pasture was lower under moderate canopy of *Albizia amara* (3.3 DM t/ha and 3.1 DM t/ha), respectively. Forage production was affected adversely with the increase in tree density in both the species.

Hazra and Tripathi (1989) studied performance of two oat genotype under moderate sized tree canopy of *Albizia lebbek, Hardwickia binata, Acacia nilotica* and *Melia azaderach* at Jhansi. The genotype OL 189 was found be superior for agroforestry system. The average oat yield was 95 per cent under *Albizia lebbek*, 90 per cent under *Hardwickia binata*, 88 per cent under *Acacia nilotica* and 74 per cent under *Melia azaderach* as compared to open plot yield.

Prasad (1990) studied grass productivity under 6-10 year old plantation of twelve different tree species *viz.*, *Acacia campylacantha, Albizia procera, Albizia lebbek, Anogeissus pendula, Cassia siamea, Cleistanthus callinus, Dalbergia sissoo, Hardwickia binata, Holoptelia integrifolia, Eucalyptus tereticornis, Pongammia pinnata, Terminalia belenica* at Jodhpur. The results indicated that

although some species had inhibitory effect on grass production, the average grass yield level of 3-4 DM t/ha from these plantations was not insignificant as this is obtained without any extra cost.

Several reports pertaining to root and shoot proportion of grass species are available. Bray (1963) found that root and shoot proportion of range and pasture grasses varied with species. Soil fertility levels, climatic conditions and variation in species diversity were identified as the other major reasons. Pandit (1984) reported wide variation in belowground/aboveground ratio of *Dicanthium annulatum* in different months from 0.27 (September) to 2.67 (June) in grazing lands at Bhavnagar. However, Chaturvedi *et al.* (1988) reported peak grass biomass (both aboveground and belowground) production during September under *Pinus roxburghii* forests in Kumaun. The average BG/AG ratio was found to be 0.37.

Bist and Kediyal (1989) studied BG/AG ratio in grass species like *Cymbopogon citratus, Vetiveria zizanioides, Saccharum maranga* and *Egrostis stolonifera* at different elevation in Central Himalaya. The BG/AG ratio varied widely from 0.16 to 0.50.

As in this study, Verma and Rao (1988) reported higher AG biomass as compared to BG biomass at grassland ecosystem on marginal land of Banthara (near Lucknow). However, Pandya and Sidha (1989) reported higher belowground biomass as compared to aboveground biomass in grazing lands at Kutch. They concluded that photosynthetic input in excess of metabolic requirement of aboveground live was probably diverted towards belowground biomass. Verma and Rao (1988) reported no definite trend of seasonal variation in BG/AG ratio in any of there study sites. However, BG biomass was reported to be effected due to rainfall and soil fertility level, especially the sodium content. There existed a strong correlation with aboveground live biomass, total community biomass and aerial net primary productivity.

The results obtained in this study on the aspect *viz.*, yield from ground vegetation at different microsite, proportion of belowground biomass etc. relate to most of the above findings. Thus biomass from ground vegetation in silvopastoral systems is largely determined by microclimate, species diversity, density and vigour in a multifactional fashion.

Standing Tree

Tree productivity is usually estimated in terms of merchantable log volume in traditional forestry. However, in silvopasture where a multiplicity of products *viz.*, foliage, branches, small and large size timber material etc. are required; estimation of biomass accumulated in different tree components is important (Applegate *et al.*, 1988).

In this study, standing tree biomass of *Albizia amara* was estimated for the three microsites based on representative tree felling during 1997 and 1998. Table 17 presents the data on standing tree biomass accumulation in different parts of *Albizia amara* (24-25 year) at different microsites.

At all the microsites, generally, higher biomass was recorded during 1998 (after 24 year growth) when compared to 1997 (after 23 year growth). This may be attributed to higher growth attained by the trees during 1998. Highest mean total biomass was recorded at microsite 4 (151.6 DM t/ha) followed by microsite 3 (121.2 DM t/ha) and microsite 2 (108.1 DM t/ha). The proportion of aerial biomass to total biomass was highest at microsite 4 (83.4 %) closely followed by microsite 3 (82.8 %) and microsite 2 (82.7 %).

Highest proportion of bole to total aerial production was recorded at MS 4 (27.0 %) followed by MS 2 (23.4 %) and MS 3 (22.3 %). The proportion of branch was highest in MS 3 (61.7 %) followed by MS 2 (58.0 %) and MS 4 (55.3 %). Highest proportion of leaf was recorded in MS 2 (17.5 %) followed by MS 4 (16.5 %) and MS 3 (14.7 %). Highest proportion of pod was recorded in MS 2 (1.3 %) closely followed by MS 4 (1.2 %) and MS 3 (1.1 %). The proportion of

Table 17
Standing tree biomass (DM t/ha) from trees of *Albizia amara* in silvopastoral system (1997-1998).

Microsite	Year	Standing Tree Biomass					
		Bole	Branch	Leaf	Pod	Root	Total
MS 2	1	20.16	51.12	15.36	1.20	19.92	107.8
	2	21.75	52.50	15.50	0.75	19.05	108.5
	Mean	20.95	51.81	15.68	0.97	19.71	108.1
MS 3	1	20.88	61.68	15.12	1.44	20.88	120.0
	2	24.00	62.25	14.50	1.00	20.75	122.5
	Mean	22.44	61.96	14.81	1.22	20.81	121.2
MS 4	1	32.64	69.36	20.88	1.44	24.72	149.0
	2	35.75	70.75	21.00	1.25	25.50	154.3
	Mean	34.19	70.05	20.94	1.34	25.11	151.6

belowground biomass to aboveground biomass was highest in MS 3 (17.2 %) followed by MS 4 (16.6 %) and MS 2 (10.6 %).

Detailed biomass studies on many trees are available from different studies (Gurumurthy *et al.*, 1984 a; 1984 b; Verma and Mishra, 1986; Chandrashekharaiah and Prabhakar, 1987; Ambasht, 1988; Singh, 1988; Kushalappa, 1988; Deb Roy, 1988 a; 1988 b; Pal and Raturi, 1989; Srivastava, 1994; Roy, 1996). However, on account of different soil and climatic conditions, plantation density and plantation age, many of these studies are not comparable with this study. However, if a comparision is made with other species like *Acacia tortilis* and *Hardwickia binata* on similar sites (Pathak *et al.*, 1988; Khan *et al.*, 1993; Singh and Gupta, 1993), the growth attained by *Albizia amara* was found to be better.

The diameter, especially the diameter at breast height (dbh) has been found to be most appropriate in determining biomass and timber volume in species like *Acacia tortilis, Hardwickia binata, Leucaena leucocephala* and *Albizia amara* (Pathak *et al.*, 1988; Khan *et al.*, 1993; Roy, 1996). Thus by simply measuring dbh an estimation about tree productivity in case of *Albizia amara* may be made for planning purposes.

The BG/AG ratio based on dry matter basis was found to vary between 0.11 to 0.17 in case of *Albizia amara* trees at this site during February/March. The BG/AG ratio in trees varies with species, age, plantation density, soil fertility, climatic conditions and species diversity (Michael, 1986).

Kaul *et al.* (1983) reported BG/AG ratio of 0.027 from 8 years old *Populus deltoides* in Tarai region of Uttar Pradesh. Murphey and Lugo (1986) found a ratio of 0.50 from a sub tropical forest (stem density 12000/ha) in Puerto Rico. Castellanos *et al.* (1991) reported a ratio of 0.42 from a dry deciduous forest (4700 tree/ha with basal area dbh of 23 m^2/ha) in Mexico. Dhyani *et al.* (1990) reported a BG/AG ratio of 0.37, 0.40 and 0.41 on young and moderately spaced trees of *Leucaena leucocephala, Eucalyptus tereticornis* and *Grewia optiva,* respectively in Doon Velly. Singh and Gupta (1993) reported a ratio of 0.28 to 0.32 from 19 year old *Hardwickia binata* on *Bhata* soils near Raipur.

Thus the BG/AG ratio recorded in this study is on a lower side, indicating more biomass allocation towards aerial parts.

Lopping of Trees

Top feed are best utilized either through browsing by livestock or by providing fresh lopped fodder to the animals. Freshly lopped leaves are also stored as dried leaves or silage. The existing practice of excessive and indiscriminate lopping of trees has resulted in the depletion of valuable fodder resources. Judicious lopping of fodder trees in silvopastures system is crucial for

maintaining pasture productivity and providing fodder and firewood during lean periods (Singh, 1982; Roy, 1992).

In this study, biomass obtained from *Albizia amara* through lopping was estimated during 1997 and 1998. Table 18 presents the data on lopped tree biomass *viz.*, branch, leaf at different microsites. Highest total lopped biomass was recorded at MS 4 (1.85 DM t/ha) followed by MS 3 (1.56 DM t/ha) and MS 2 (1.03 DM t/ha). The proportion of mean leaf production was highest at MS 2 (42.7 %) followed by MS 4 (41.6 %) and MS 3 (41.0 %). Higher levels of lopped biomass was obtained during 1998 when compared to 1997. This may be attributed on account of two reasons; (i) heavier lopping practiced on these stand to open up the canopy during 1997 and (ii) higher rainfall receipt during 1998.

Table 18
Lopped tree biomass (DM t/ha) from trees of *Albizia amara* in silvopastoral systems (1997 and 1998).

Microsite	Year	Lopped Biomass		
		Branch	Leaf	Total
MS 2	1	0.23	0.15	0.38
	2	0.95	0.73	1.68
	Mean	0.59	0.44	1.03
MS 3	1	0.33	0.21	0.54
	2	1.51	1.08	2.59
	Mean	0.92	0.64	1.56
MS 4	1	0.37	0.24	0.61
	2	1.79	1.30	3.09
	Mean	1.08	0.77	1.85

The results indicate that through judicious lopping management additional forage (0.44 – 0.77 DM t/ha) and firewood (0.59 – 1.08 DM t/ha) yields could be obtained from mature *Albizia amara* stands. This management has also important implication in increasing the pasture productivity as a result of opening up of the canopy. This is evident from the results presented in Table 18.

The published literature on lopping management of fodder trees is scanty. Most of the information on such aspects is available for *Prosopis cineraria* where annual loppping up to 2/3 of the canopy has been recommended (Bhimaya *et al.*, 1964; Ganguly *et al.*, 1964; Srivatava 1978; Ghosh, 1980). Some information is also available in respect of *Quercus* (Gorrie, 1937); *Albizia procera* (Laurie, 1945; Roy, 1991); *Acacia nilotica* (Deb Roy *et al.*, 1982); *Acacia tortilis, Albizia amara, Hardwickia binata, Albizia lebbek, Dichrostachys cinerea* (Roy, 1991).

The biomass obtained as a result of lopping *Albizia amara* trees is on a higher side when compared to lopped biomass obtained from other species *viz.*, *Acacia tortilis, Albizia lebbek, Albizia procera, Dichrostachys cinerea* on similar site (Roy, 1991; Singh *et al.*, 1992; Pathak and Roy, 1994). This could be attributed due to high leafy proportion and very high regeneration ability.

Total System Productivity

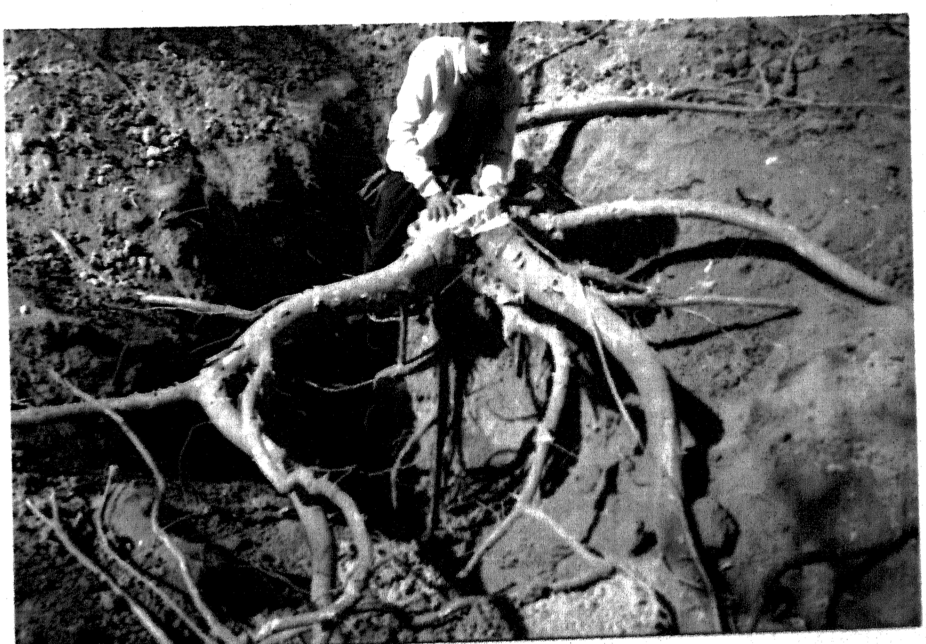
Although work on silvopasture was initiated in 1960s, the earlier information was generated in piece meal. So, comparatively less information is available on evaluation on total system productivity in a given rotation (Pathak and Roy, 1994).

In this study, an attempt was made to project aboveground, belowground and total biomass of different microsites based on the data set generated during 1997 and 1998. Table 19 presents the data on aboveground biomass production at the four microsites.

In open situation (without tree), average forage production of 3.61 DM t/ha/yr was recorded. All this forage came from the ground vegetation during July

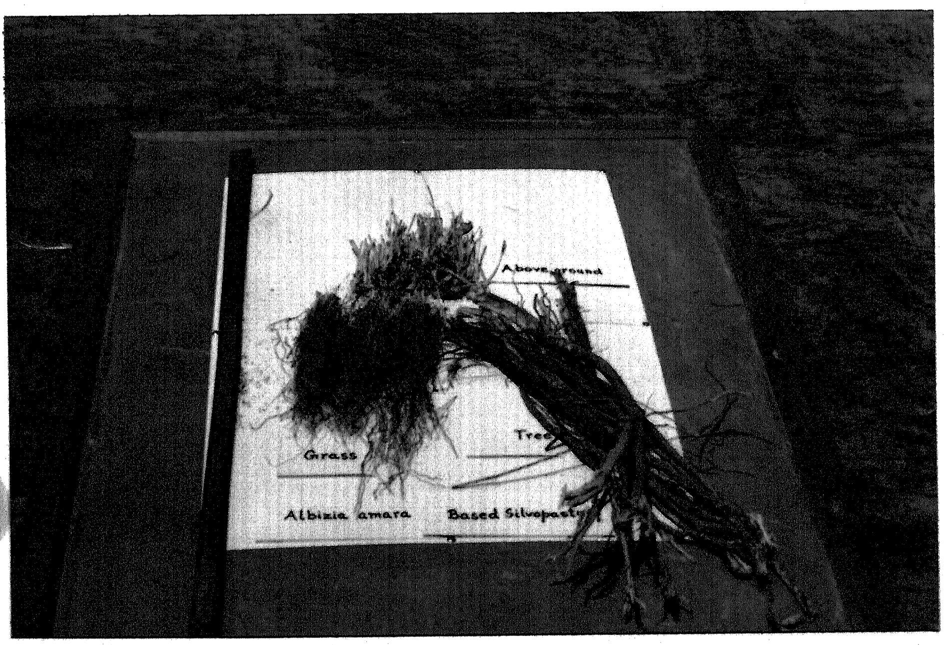
Plate 3

Lopping of *Albizia amara* at the study site



A view of the excavated root system of *Albizia amara* at the study site

A view of the excavated monolith for estimating belowground biomass of the understory



The above and belowground components obtained from a monolith (in dry season)

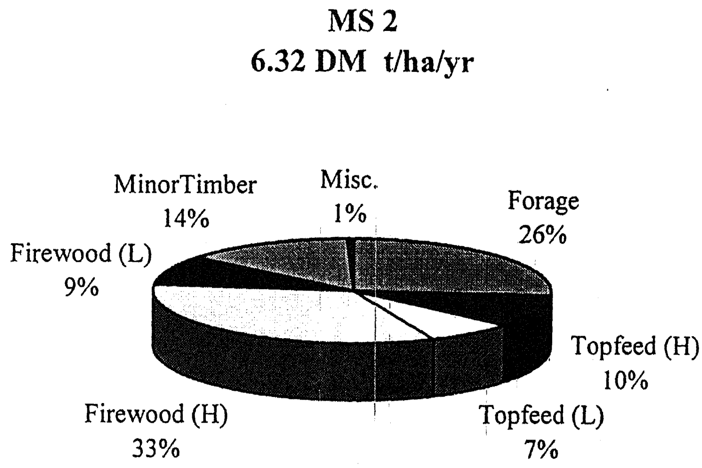
to November/December. The forage supply (pasture component) decreased in silvopasture with increase in tree density. This reduction was in the range of 54.3 per cent to 71.5 per cent. However, such systems yielded top feeds during January to April. The availability of top feed increased from 1.08 DM t/ha/yr to 1.62 DM t/ha/yr with the increase in tree density. Thus effective decrease in forage supply under silvopasture was only in the range of 24.4 per cent to 26.6 per cent (Table 19).

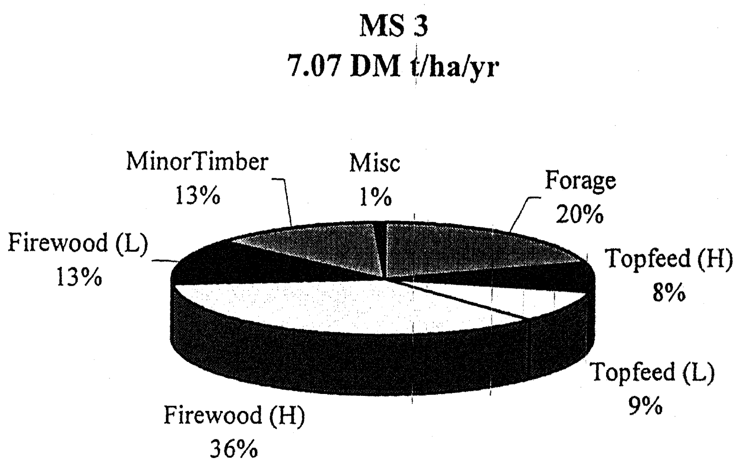
Table 19
Total aboveground biomass production (DM t/ha/yr) at the different microsites of study (1997-1998).

Microsite	Forage	Topfeed	Firewood	Minor Timber	Pod &Seed	Total
MS 1	3.61	--	--	--	--	3.61
MS 2	1.65	1.08	2.70	0.85	0.04	6.32
MS 3	1.43	1.24	3.44	0.91	0.05	7.07
MS 4	1.03	1.62	3.93	1.40	0.05	8.03

However, the marginal decrease in forage supply under silvopasture has been well compensated by the other tree products *viz.*, firewood (2.70 – 3.93 DM t/ha/yr), minor timber (0.85 – 1.40 DM t/ha/yr), pod and seed (0.04 – 0.05 DM t/ha/yr). Thus aboveground productivity under silvopastures increased from 1.75 to 2.22 times when compared to only pasture land use system (Table 19).

The trend of aerial productivity from mature *Albizia amara* (> 24 year) based silvopastures at different microsites is presented in Fig. 11. The proportion of tree products increased from 74 per cent to 87 per cent, with the increase in tree stocking rate per ha. On final harvest, proportion of wood (minor timber + firewood) increased from 47 to 55 per cent with the increase in tree density.





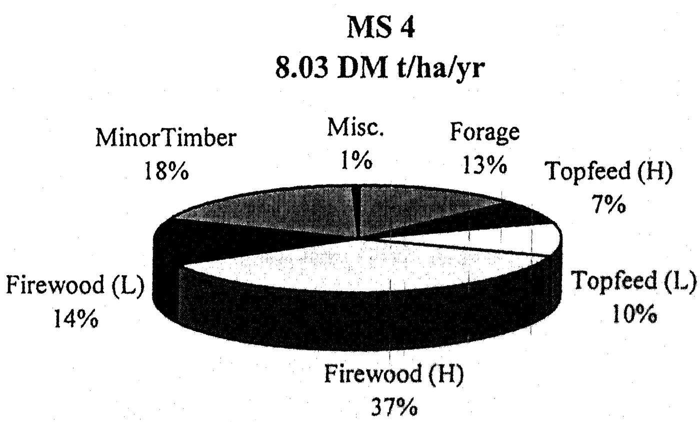


Fig. 11
Aerial productivity (DM t/ha/yr) from *Albizia amara* (> 24 year) based silvopastures at different microsites (H - on harvest; L - on lopping).

However, proportion of top feed obtained on account of final harvest decreased from 7 to 10 per cent with the increase in tree density.

Lopping on an annual basis maintained higher top feed and firewood supply with the increase in tree density. The proportion of top feed supplies increased from 7 per cent to 10 per cent and firewood supplies from 9 per cent to 14 per cent.

Some studies on assessment of total silvopasture system productivity on comparatively shorter rotation (10-12 years) are available. These studies indicated aerial productivity in the range of 6-10 DM t/ha/yr depending on the site characteristics (Singh *et al.*, 1990; Singh *et al.*, 1992; 1993; 1994; Singh and Roy, 1993; Pathak and Roy, 1994; Singh and Roy, 1998; Mal and Roy, 1999). In most of the studies, proportion of forage from pastures varied from 40 to 45 per cent. However, in this study, proportion of forage was quit low. This may be attributed to; (i) densely spreading tree canopy at the maturity; (ii) computation were made from the data recorded during canopy closure stage only. Apart from this factors, aerial system productivity matches with the earlier data. However, as this productivity has been calculated on a much longer rotation the overall bio productivity of *Albizia amara* based systems appears to be quite high.

Table 20 presents data on belowground biomass productivity at the four microsites. The belowground biomass varied from 1.20 to 1.30 DM t/ha/yr. There was not much difference in belowground biomass production at microsites 1 to 3. Only marginal increase (8 %) in belowground biomass was recorded at micrisite 4.

Table 21 presents data on total biomass productivity (aboveground + belowground) at the four microsites. Highest total system productivity was recorded at MS 4 (9.33 DM t/ha/yr) followed by MS 3 (8.27 DM t/ha/yr), MS 2 (7.52 DM t/ha/yr) and MS 1 (4.82 DM t/ha/yr). Thus total system productivity under silvopastures increased from 1.56 to 1.93 times when compared to only pasture land use system (Table 21).

Table 20
Total belowground biomass production (DM t/ha/yr) at the different microsites of study (1997-1998).

Microsite	Pasture	Tree	Total
MS 1	1.21	--	1.21
MS 2	0.40	0.80	1.20
MS 3	0.35	0.85	1.20
MS 4	0.28	1.02	1.30

Table 21
Total productivity (DM t/ha/yr) at the different microsites of study (1997-1998).

Microsite	Aboveground	Belowground	Total
MS 1	3.61	1.21	4.82
MS 2	6.32	1.20	7.52
MS 3	7.07	1.20	8.27
MS 4	8.03	1.30	9.33

A few composite samples were drawn at the time of grass/top feed harvest. Major attributes of forage quality *viz.*, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) were got analyzed from Central Analytical Laboratory of IGFRI.

Table 22 presents data on average forage quality of pasture species and top feed. The top feed maintained much higher level of CP (16.2 %) when compared to the pasture component (3.9 %). The NDF and ADF values were higher (63.6, 47.0) in the pasture component when compared to top feed (36.2, 37.6).

Table 22
Average forage quality (%) in different components at the study site.

Attributes	Pasture	Topfeed
CP	3.9	16.2
NDF	63.6	36.2
ADF	47.0	37.6

A lot of variability in average forage quality attributes like CP, NDF and ADF has been reported in many studies. Such variations are mainly attributed to the effect of seasonality and site factors (Singh, 1982; Minson, 1990; Norton and Poppi, 1995). Also, these studies were conducted in isolation, only component wise.

In one study where chemical composition of forage was studied in open and fenced plots, CP during September was more in fenced plots when compared to open. However, during October in control situation the order was reverse but fenced plots having trees had more CP (Singh *et al.*, 1992). Although such studies were not undertaken in the present investigation, consistently higher average CP level in top feeds indicate improvement in forage quality in silvopastures (Singh *et al.*, 1993; 1994).

PART IV

NUTRIENT TURNOVER

The terrestrial ecosystem productivity is regulated by a number of environmental factors including radiation, temperature, water and availability of nutrients. The availability of nutrients is also affected by these environmental factors and in most forests productivity is directly related to nutrient availability and uptake (Binkley, 1986).

The nutrients are elements required to complete plants life cycle. About 95 per cent of plant biomass (as dry weight basis) is composed of Carbon, Oxygen and Hydrogen. The remaining elements are classified as macro nutrients (nitrogen, sulphur, potassium, phosphorus, calcium and magnesium) and micro nutrients (manganese, iron, chlorine, copper, zinc, molybdenum and boron). Each of these elements has unique pattern of sources, transformation and availability to plants under varying environmental condition (Mengel and Kirkby, 1982).

Since, carbon, oxygen and hydrogen are so abundant they are not usually included in discussion on nutrient cycle. Nitrogen most commonly limits productivity of terrestrial ecosystems. Besides nitrogen, phosphorus (being part of every energy transformation), potassium (activating many enzymes), calcium (in connecting organic molecules) are also important in most of such ecosystems (Bruijnzel, 1991).

In this study, nutrient turnover under silvopastures was assessed at all the three microsites. Since, grasses were utilized through cut and carry system on an annual basis, a matching study at microsite 1 could not be undertaken. The results obtained from studies related to assessment of litter production (from trees); nutrient analysis in litter and standing vegetation; pattern of nutrient lockup; recyclable nutrients and litter decomposition at different microsites being discussed in this part.

Litter Production

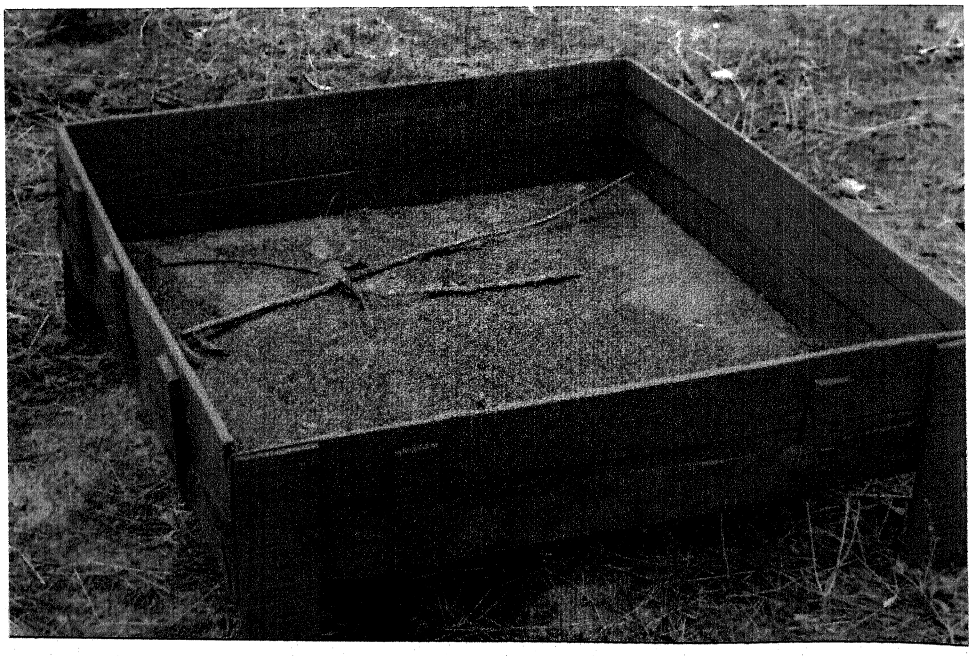
In tree based ecosystem like silvopastoral system, the interaction and sequential processes of litter fall, its decomposition and subsequent mineralization of nutrient play a key role in sustaining productivity. The rate of litter production, decomposition and mineralization are complex processes and depend upon various factors of physico-chemical environment and the quantity and quality of organic residues/litter. The amount and pattern of leaf fall varies with the types of tree species, tree growth, age, density and canopy characteristics. An understanding of litter fall dynamics has important implication in relation to nutrient cycling and in assessment of potential role of trees in ameliorating soil under agroforestry/silvopastures (Golley, 1978; Malik and Prakash, 1993; George and Mohan Kumar, 1998).

The trend of seasonality in litter production of *Albizia amara* at different microsites during 1997 and 1998 are depicted in Figs 12 and 13, respectively. It is evident from the figures that most of the litter fall (around 87 %) was concentrated during January to June when compared to July to December at all the microsites during both the years. Peak litter production was recorded during March closely followed by May, April and February at all the microsites. Total litter production during 1997 varied from 5.0 to 7.71 t/ha with the increase in tree density. In 1998, generally higher level of litter production was recorded. This could be attributed to more canopy spread and production from trees during 1998.

Leaves contributed about 70 per cent of the total litter fall receipt during both the years. It was followed by miscellaneous litter production (17 %) and branch litter (13 %). Leaf litter was recorded during all the months whereas branch and miscellaneous litter production were limited to some months only. Generally a negligible amount of branch and miscellaneous litter was produced during July to December. Peak branch and miscellaneous litter fall were generally recorded during May (Figs 12 and 13).

Plate 5

Litter trap (1mx1m) for litter fall studies at the experimental site



A close-up view showing fallen litter in litter trap

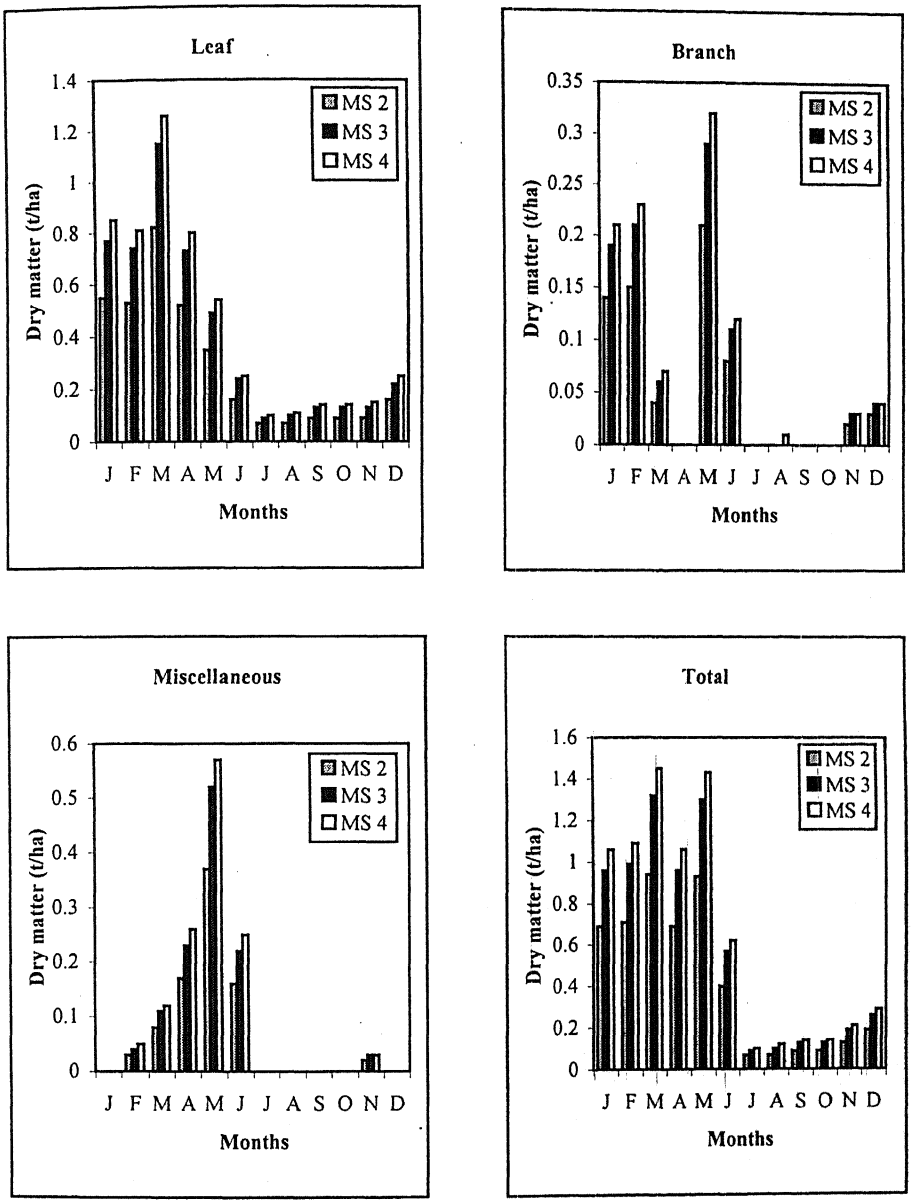


Fig. 12
Trend of seasonality in tree litter *(Albizia amara)* production at different microsites during 1997.

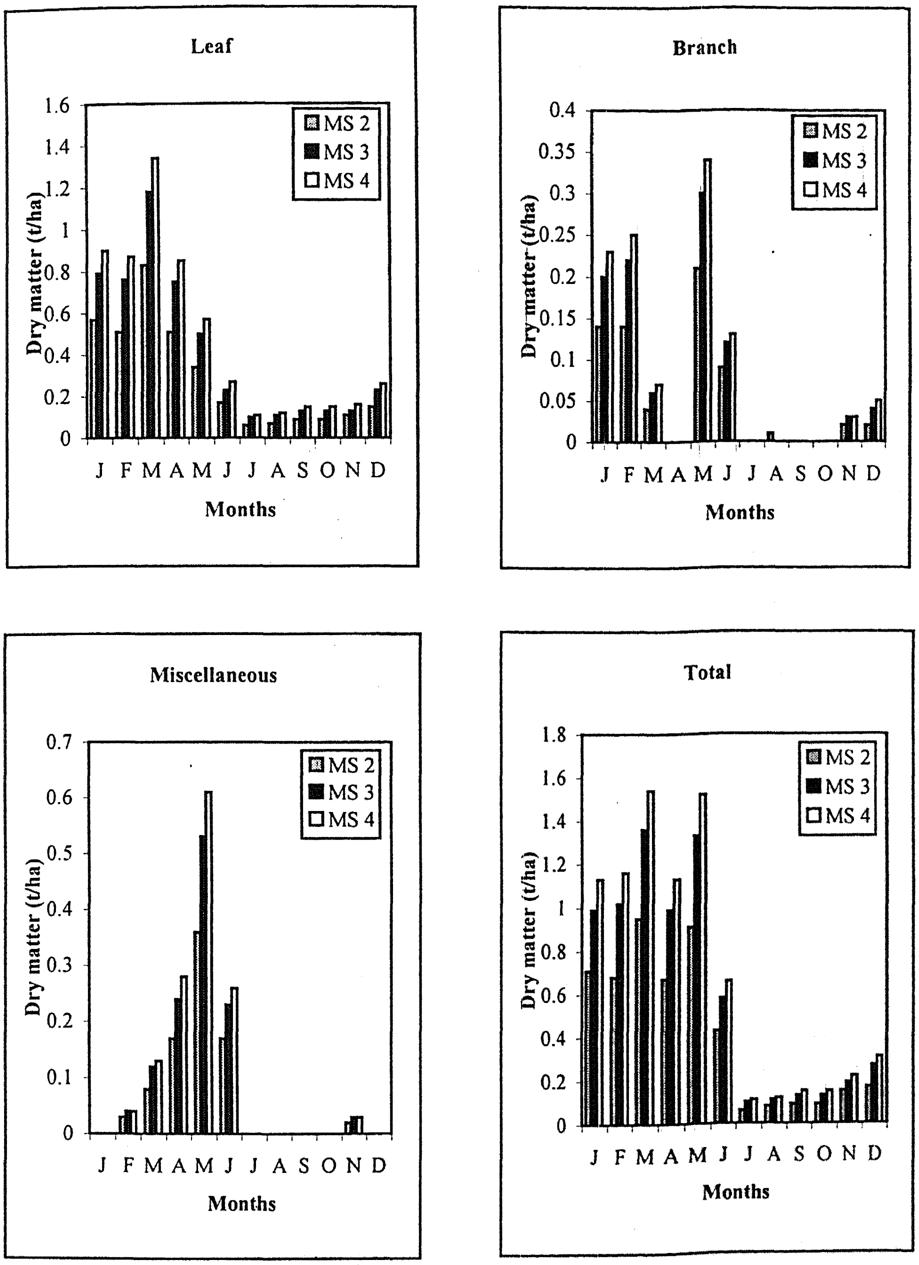


Fig. 13
Trend of seasonality in tree litter (*Albizia amara*) production at different microsites during 1998.

Litter production based on two years data at the three microsites of the study is presented in Table 23. At this growth stage total litter productivity varied from 5.00 to 7.95 t/ha/yr with the increase in tree density. During 1997 significant difference was found in leaf litter production between microsite 2 and microsite 4 only. However, during 1998 significant difference in leaf litter production was observed between all the three microsites. The litter production on account on branch and miscellaneous tree parts at different microsites showed an increasing trend with the increase in tree density. However, the differences were not significant. As in leaf litter production, during 1997 significant difference was found in total litter production between microsite 2 and microsite 4 only. In 1998 significant difference in total litter production was observed between all the three microsites. Thus, it shows that especially the leaf litter play a major role in structure and functioning of a terrestrial ecosystem.

The pattern of litter fall and subsequent nutrient release has been more extensively studied for temperate areas when compared to tropical areas (Bray and Gorham, 1964). However, in India, several studies on annual litter production are available from deciduous forests and old plantations (Puri, 1953; Bhatnagar, 1968; Singh, 1968; Gaur and Pandey, 1971; Subba Rao *et al.*, 1972; George, 1982; Naik and Srivastava, 1985; Prasad and Mishra, 1985; Rajvanshi and Gupta, 1985; Girolkar and Naik, 1987; Chaubey *et al.*, 1988; Pandey and Sharma, 1988; Paulsamy *et al.*, 1992; Joshi, 1993; Singh and Gupta, 1993; Hosur *et al.*, 1997; Mishra and Nisanka, 1997; Jammaludden and Kumar, 1999). The leaf litter production varied from 1.08 to 17.3 t/ha in deciduous forests of India depending upon site quality, latitude, tree species and their density. Recently litter production under multipurpose tree species in agroforestry situation has been studied by some workers (Malik and Prakash, 1993; Singh and Keshwa, 1993). Under 6 years old plantation (500 tree/ha) of *Bombax ceiba, Albizia lebbek, Terminalia arjuna, Dalbergia sissoo* and *Melia azaderach*; the annual litter fall varied from 0.7 to 1.0 t/ha (Malik and Prakash, 1993).

Table 23
Annual litter production (t/ha) from *Albizia amara* in silvopastoral systems (1997-1998).

Microsite	Leaf	Branch	Misc.	Total
		Year 1		
MS 2	3.5	0.6	0.9	5.0
MS 3	4.9	0.8	1.3	7.0
MS 4	5.4	1.1	1.2	7.7
CD (<0.05)	1.8	NS	NS	2.3
		Year 2		
MS 2	3.4	0.8	0.8	5.0
MS 3	5.1	0.9	1.2	7.2
MS 4	5.7	1.2	1.3	8.2
CD (<0.05)	1.6	NS	NS	2.1
		Mean of Two Years		
MS 2	3.45	0.70	0.85	5.00
MS 3	5.00	0.85	1.25	7.10
MS 4	5.55	1.15	1.25	7.95

Bray and Gorham (1964) have shown an inverse relationship between annual leaf litter production and latitude of the locality. As per their calculations the potential annual leaf litter production on this site could be 6.32 t/ha. Thus peak annual litter production at microsite 4 (5.77 t/ha) is still less by about 9 per cent of the potential. This could be attributed to poor site quality.

Nutrient Concentration

The range of variation in nutrients *viz.*, nitrogen, phosphorus, potassium, calcium in various plant parts of standing vegetation in silvopasture based on *Albizia amara* across the microsites are shown in Tables 24 and 25. The tree parts maintained higher range of nitrogen concentration when compared to pasture components. In trees, highest average concentration of nitrogen was recorded in pods (3.20 %) followed by leaf (2.67 %), branch (1.31 %), root (0.89 %) and bole (0.29 %). The aboveground pasture component had higher nitrogen concentration (0.66 %) when compared to the belowground component (0.47 %). Like nitrogen, higher range of phosphorus concentration was recorded in tree parts when compared to pasture components. In trees, highest average phosphorus concentration was recorded in pod (0.16 %) followed by leaf (0.13 %), root (0.09 %), branch (0.04 %) and bole (0.02 %). The aboveground pasture components had higher phosphorus concentration (0.02 %) when compared to the belowground components (0.01 %) (Table 24).

Pods and leaves of the tree generally maintained higher range of potassium concentration when compared to pasture components. In trees, highest average concentration of potassium was recorded in pods (1.00 %) followed by leaf (0.73 %), branch (0.53 %), root (0.41 %) and bole (0.16 %). The aboveground pasture components had higher potassium concentration (0.66 %) when compared to belowground components (0.41 %). Like potassium, the leaf and pods maintained higher range of calcium concentration when compared to pasture components. Highest average concentration of calcium was recorded in

Table 24
Mean nutrient content (%) in different plant parts of *Albizia amara* based silvopastoral system at the study site (N and P).

Component	Plant Part	Nitrogen Range	Av.	Phosphorus Range	Av.
Pasture					
	AG	0.49-0.78	0.66	0.01-0.03	0.02
	BG	0.31-0.60	0.47	0.01-0.02	0.01
Tree					
	Leaf	2.17-3.46	2.67	0.12-0.16	0.13
	Pod	3.23-3.83	3.20	0.15-0.18	0.16
	Bole	0.18-0.36	0.29	0.02-0.03	0.02
	Branch	1.03-1.43	1.31	0.02-0.06	0.04
	Root	0.69-0.98	0.89	0.07-0.11	0.09

Table 25
Mean nutrient concentration (%) in different plant parts of *Albizia amara* based silvopastoral system at the study site (K and Ca).

Component	Plant Part	Potassium Range	Av.	Calcium Range	Av.
Pasture					
	AG	0.33-0.61	0.66	0.63-0.97	0.89
	BG	0.32-0.54	0.41	0.53-0.89	0.83
Tree					
	Leaf	0.68-0.89	0.73	1.73-2.19	1.93
	Pod	0.93-1.10	1.00	1.07-1.16	1.11
	Bole	0.13-1.18	0.16	0.27-0.36	0.31
	Branch	0.47-0.59	0.53	0.54-0.69	0.61
	Root	0.37-0.47	0.41	0.42-0.53	0.47

leaf (1.93 %) followed by pod (1.11 %), branch (0.61 %), root (0.47 %) and bole (0.31 %). The aboveground pasture components maintained marginally higher calcium concentration (0.89 %) when compared to the belowground components (0.83 %) (Table 25).

The concentration of all the nutrients *viz.*, N, P, K and Ca in leaf litter was lower when compared to standing leaf. Excepting P, K and Ca in branch and P and Ca in miscellaneous, lower concentration of all the nutrients was recorded in branch and miscellaneous litter when compared to corresponding live standing vegetation. In leaf litter, highest reduction was recorded in case of nitrogen (33 %) followed by phosphorus (8 %) and potassium (7 %). In branch litter, highest reduction was in case of nitrogen (29 %). In miscellaneous litter, highest reduction was in case of nitrogen (33 %) followed by potassium (7 %).

The range of variation in nutrients *viz*., nitrogen, phosphorus, potassium and calcium in various litter parts of *Albizia amara*, across the microsites, is shown Table 26. The miscellaneous litter contained higher concentration of all the nutrients, excepting calcium which was higher in leaf. Similar trend of nutrient concentration has been reported by Hosur *et al*. (1997) in six different tree species *viz*., *Tectona grandis, Dalbergia sissoo, Acacia catechu, Dendrocalamus strictus, Eucalyptus tereticornis* and *Casuarina equisetifolia.*

Nutrient accumulation in individual plant tissues of standing vegetation is usually a reflection of soil fertility status. The photosynthetic capacity of foliage is usually correlated with nutrients, especially of nitrogen (Natar, 1972; Field and Mooney, 1986).

In tropics, nutrient concentration is usually higher in leaf/pod. It appears that in these situations relatively more of the photosynthetate produced by trees is allocated to leaves (Whittaker and Likens, 1975). Similar observation have been reported by Sharma *et al.* (1988) in old *Dalbergia sissoo* plantation in India. They found that almost all nutrients, excepting calcium were higher in the foliage when compared to other tree components. Montagnini *et al*. (1991) and Montagnini and

Sancho (1994) reported similar trend in youngs plantation of several multipurpose tree species *viz.*, *Vochysia hondurensis, V. ferruginea, Styphnodendron excelsum* and *Hyeronima alchorneoides* in humid lowlands of Costa Rica. However, in this study, pods maintained a higher level of nitrogen, phosphorus and potassium concentration when compared to leaf. However, leaf maintained higher calcium concentration when compared to pod. The production of pods in this species is quite low when compared to leaf. In such a situation the leaves have the most important role to play in nutrient turnover. Generally lower level of nutrient concentration is reported in litter parts when compared to their aboveground counter parts (Raghubanshi *et al.*, 1992; Hosur *et al.*, 1997; Jamaludheen and Kumar, 1999). The present study also confirms this finding.

Table 26
Mean nutrient concentration (%) in different litter parts of *Albizia amara* at the study site.

Nutrients	Leaf	Litter Part Branch	Misc.
N	1.78±1.13	0.93±0.38	2.13±0.14
P	0.12±0.01	0.07±0.02	0.18±0.03
K	0.68±0.19	0.64±0.11	0.93±0.13
Ca	1.93±0.21	1.06±0.17	1.19±0.17

Nutrient Accumulation in Standing Biomass

Trend of nutrient accumulation by the ground vegetation in aboveground and belowground parts is depicted in Table 27. The accumulation of all the nutrients was higher in aboveground parts. The accumulation of nutrients decreased from microsite 2 to microsite 4, primarily on account of less pasture yield with increase in tree density.

Table 27
Nutrient accumulation (kg/ha/yr) by the ground vegetation at the study site (1997-1998).

System	Nitrogen		Phosphorus		Potassium		Calcium	
	AG	BG	AG	BG	AG	BG	AG	BG
MS 2	8.7	1.3	0.2	0.02	6.4	1.1	11.8	2.4
MS 3	7.7	1.2	0.2	0.02	5.4	1.0	10.4	2.1
MS 4	5.0	0.8	0.1	0.01	3.5	0.7	6.7	1.5

Trend of nutrient accumulation in different parts of *Albizia amara* (> 24 years) at various microsites is depicted in Table 28. The accumulation of nutrients increased from microsite 2 to microsite 4, primarily on account of more total tree biomass with increase in tree density. Highest accumulation of all the nutrients was in branch followed by leaf, root, bole and pod.

Highest accumulation of nutrients was registered in case of nitrogen (1338 –1842 kg/ha) followed by calcium (768 – 1070 kg/ha), potassium (506 – 695 kg/ha) and phosphorus (63 – 106 kg/ha). Most of this nutrients was locked up in aerial parts. The proportion of nutrient lockup in aerial parts varied from 86 to 88 per cent, 72 to 79 per cent, 81 to 85 per cent and 87 to 89 per cent in case of nitrogen, phosphorus, potassium and calcium, respectively. Similar trends of nutrient accumulation has been reported from 24 year old *Dalbergia sissoo* plantation (Tewari, 1994 a). Raizada and Padmaiah (1993) reported huge accumulation of nutrients in plantation of *Leucaena leucocephala, Acacia nilotica, Eucalyptus* hybrid and *Azadirachta indica.*

Thus, heavy thinning in natural forests or plantations results in removal of soil nutrient pools besides many other effects *viz.*, chemical and physical soil factors, nutrient supply, root dynamics, decomposition rate, soil biota (Baath, 1980; Seasted and Crossley, 1981; Vitousek and Matson, 1985). There are several reports of about depletion of soil nutrients of as a result of large scale tree

Table 28
Nutrient accumulation (kg/ha) in *Albizia amara* (> 24 years) at the study site (1997-1998).

Microsite	Bole	Branch	Plant Part Leaf	Pod	Root
			Nitrogen		
MS 2	60.7	678.7	391.9	31.0	175.4
MS 3	65.0	811.6	395.4	39.0	185.2
MS 4	99.1	917.6	559.0	42.8	223.4
			Phosphorus		
MS 2	4.1	20.7	19.0	1.5	17.7
MS 3	4.4	24.7	19.2	1.9	18.7
MS 4	6.8	28.0	27.2	2.1	22.5
			Potassium		
MS 2	33.5	274.5	107.1	9.7	80.8
MS 3	35.9	328.3	108.1	12.2	85.3
MS 4	54.7	371.2	152.8	13.4	102.9
			Calcium		
MS 2	64.9	316.0	283.3	10.7	92.6
MS 3	69.5	377.9	285.8	13.5	97.8
MS 4	105.9	427.3	404.1	14.8	118.0

harvesting. For instance, Nwoboshi (1980) reported 10-25 per cent reduction in soil N pools as a result of heavy thinning in teak plantations in Nigeria. Similarly, Raghubanshi *et al.* (1992) reported the loss of soil organic carbon and total N by 13 and 20 per cent, respectively as a result of the harvesting of bamboo.

The importance of micronutrient accumulation in vegetation component has been discussed by Andriesse and Schelhaas (1977). They concluded that in all systems the maintenance of tree vegetation during cropping period is probably crucial for preventing critical initial loss of nutrients. The results obtained in this study confirm this.

Recyclable Nutrients

The potential recyclable nutrients through litter of *Albizia amara* are presented in Table 29. Returns of nitrogen through litter fall ranged from 86.0 to 136.1 kg/ha with the increase in tree density. Similar returns in case of phosphorus, potassium and calcium were in the range of 6.1 to 9.7 kg/ha, 42.3 to 56.6 kg/ha and 84.1 to 134.1 kg/ha, respectively. Major proportion of nutrient return was through leaf. It accounted for 72 to 73 per cent in case of nitrogen, 67 to 69 per cent in case of phosphorus, 67 to 71 per cent in case of potassium and 79 to 80 per cent in case of calcium. Next in order was miscellaneous litter that contributed 19 to 21 per cent in case of nitrogen, 23 to 25 per cent in case of phosphorus, 18 to 23 per cent in case of potassium and 11 to 12 per cent in case of calcium. Similar results have also been reported for different plantations and forests in Uttar Pradesh (George, 1986) and Karnataka (Sugur, 1989; Hosur *et al.*, 1997).

These results indicate that ground floor under silvopastures is an important place for accumulation and recycling of nutrients. The nutrients in litter were equivalent to 7 to 15 per cent of nutrients contained in aboveground biomass, depending on specific nutrients and microsites. These values are on a lower side compared to the value reported by Wang *et al.* (1991) in tropical situations. They

Table 29
Potential recyclable nutrients (kg/ha) through litter of *Albizia amara* (>24 years) at the study site (1997-1998).

Microsite	Litter			
	Leaf	Branch	Misc.	Total
		Nitrogen		
MS 2	61.4	6.5	18.1	86.0
MS 3	89.0	7.9	26.6	123.5
MS 4	98.8	10.7	26.6	136.1
		Phosphorus		
MS 2	4.1	0.5	1.5	6.1
MS 3	6.0	0.6	2.2	8.8
MS 4	6.7	0.8	2.2	9.7
		Potassium		
MS 2	29.9	4.5	7.9	42.3
MS 3	34.0	5.4	11.6	51.0
MS 4	37.7	7.3	11.6	56.6
		Calcium		
MS 2	66.6	7.4	10.1	84.1
MS 3	96.5	9.0	14.9	120.4
MS 4	107.1	12.1	14.9	134.1

found that with the exception of potassium, nutrients in forest floor litter were equivalent to a large proportion (16-50 %) of nutrients contained in the aboveground biomass. They concluded that if litter were left in floor after harvest, it would represent a substantial reservoir of nutrients for the next rotation. Montagnini and Sancho (1994) obtained similar results under plantation of *Styphnodendron excelsum, Vochysia hondurensis, V. ferruginea* and *Hyeronima alchorneoides* at the Atlantic lowlands of Costa Rica. They found that forest floor was particularly important for recycling of nitrogen, calcium, magnesium and phosphorus at that site.

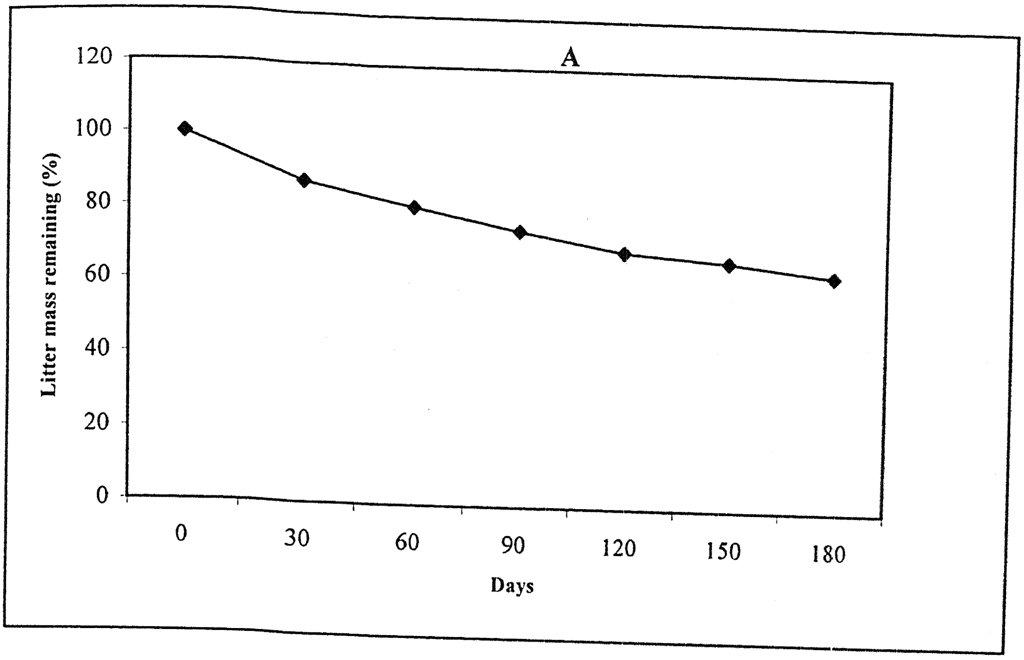
Silvopastures have potential to ameliorate productivity of degraded lands because of a consequence of several interactions on account of tree plantation with their immediate surrounding. The most significant among these is the production of litter and nutrient recycling through it. This helps in build up of organic matter and important nutrient elements in the soil (Princely and Swift, 1986). It is also reported to protect soil from erosion impact of rains and hence reduces surface water runoff (Bell, 1973).

Leaf Litter Decomposition

Leaf litter is the most important component of litter for organic matter, energy and nutrient release in forest ecosystems. The litter reaching forest floor decay and gradually become incorporated into the upper horizon of mineral soil through activity of soil organisms (Macfadyen, 1963).

Laboratory Condition

Trends of loss in litter mass and nutrient release in leaf litter of *Albizia amara* after decomposition in controlled laboratory condition for 180 days are depicted in Fig. 14. In a period of 180 days only 64.4 per cent of leaf litter biomass remained in the bags. As a result of mass loss the concentration of all the nutrients decreased with time. Maximum reduction at 180 days was recorded in



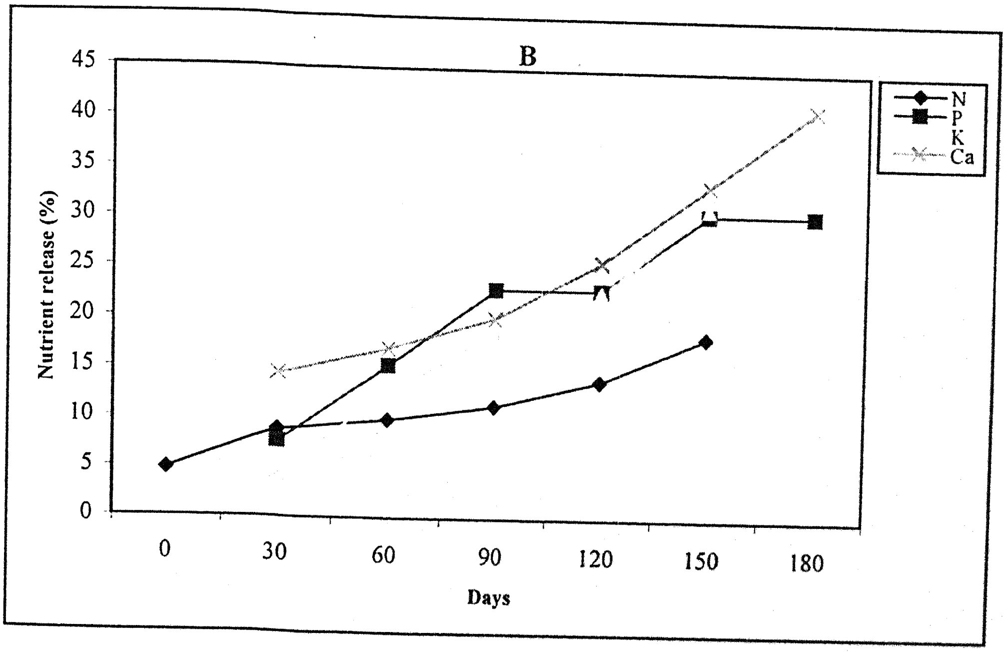


Fig. 14

A. Trend of litter mass remaining in tree leaf litter of *Albizia amara* after decomposition in laboratory condition.

B. Trend in nutrient release (%) by decomposing tree leaf litter of *Albizia amara* in laboratory condition.

case of calcium (41.5 %) followed by potassium (38.6 %), phosphorus (30.8 %) and nitrogen (18.5 %).

Field Condition

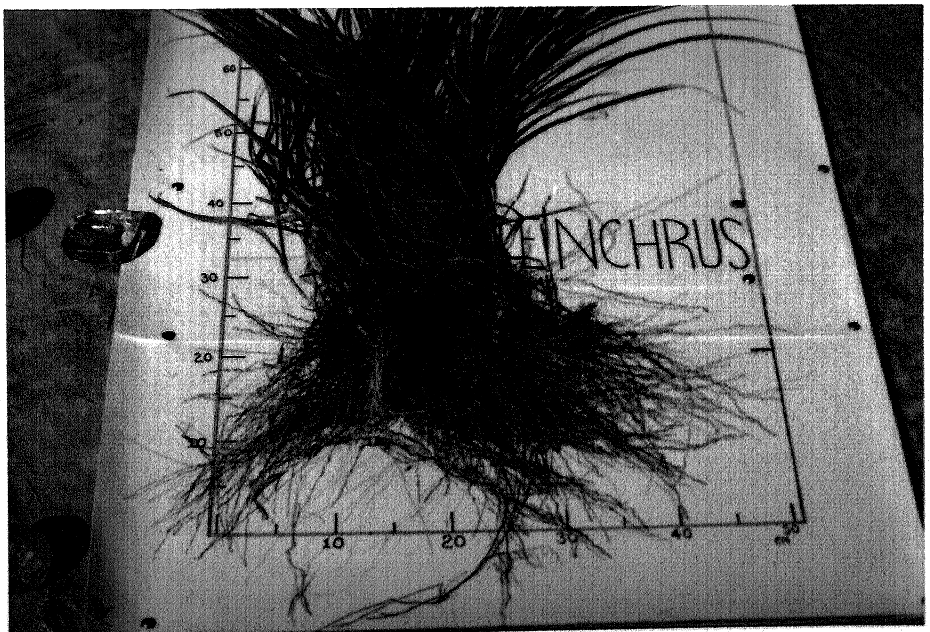
The trend of loss in litter mass (at different microsites) and nutrient release in leaf litter of *Albizia amara* after decomposition in field condition for 24 months are depicted in Fig. 15. In a period of 24 months 16.1 to 25.6 per cent of leaf litter remained in the bags. A trend of increased rate of decomposition was observed with the increase in tree density. As a result of mass loss the concentration of all the nutrients decreased with time. Maximum reduction at 24 months was recorded in case of potassium (73 %) closely followed by nitrogen (71 %), phosphorus (69 %) and calcium (66 %).

Generally, rapid rate of leaf litter decomposition was observed during rainy season. This is comparable with reports in tropical forests (Madge, 1965), tropical rain forests (Cormforth, 1970), tropical dry deciduous forests (Rajvanshi and Gupta, 1980), montane oak forest of Garhwal Himalayas (Pant and Tewari, 1992), agroforestry plantation in lowlands of Costa Rica (Montagnini *et al.*, 1993).

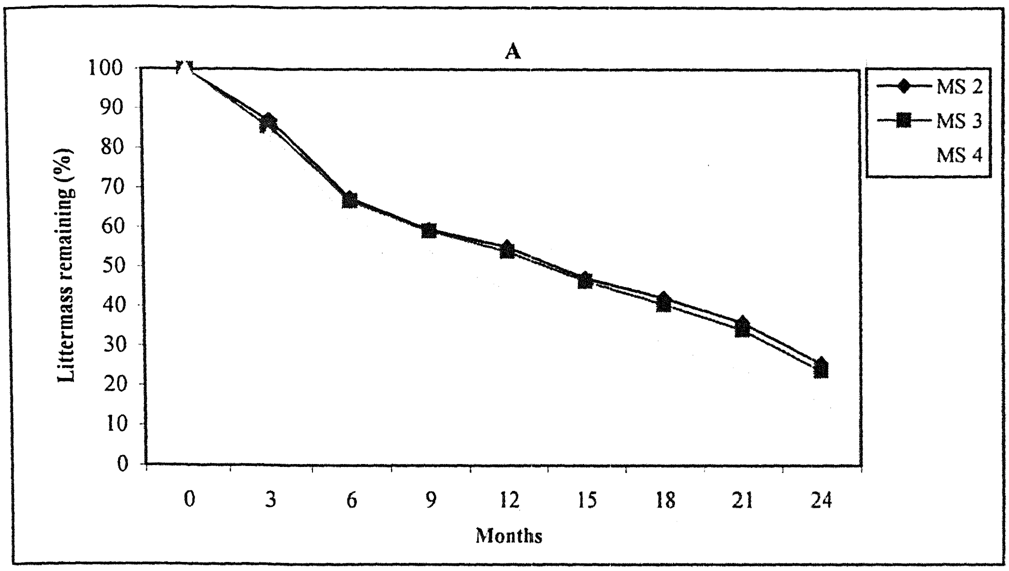
The high rate of decomposition in rainy season could be attributed to suitable temperature and moisture condition for the activity of decomposers (microorganisms) and frequent rain source for leaching of water soluble substances (Alexander, 1977). The higher decomposition rate at microsite 4 followed by microsite 3 and 2 in that order may be attributed to more favorable microclimatic condition for the activity of decomposers under dense plantation.

The residual moisture of rainy season and moderate temperature in early months of winter may be responsible for higher decomposition rate in winter when compared to spring. Relatively lower rate of decomposition during spring and summer season may be due to paucity of soil water resulting from low rainfall and large insolation period.

Placement of litter bags at the experimental site for estimating loss in litter mass



Growth of *Cenchrus ciliaris* a major grass species at the study site (Also showing the root system)



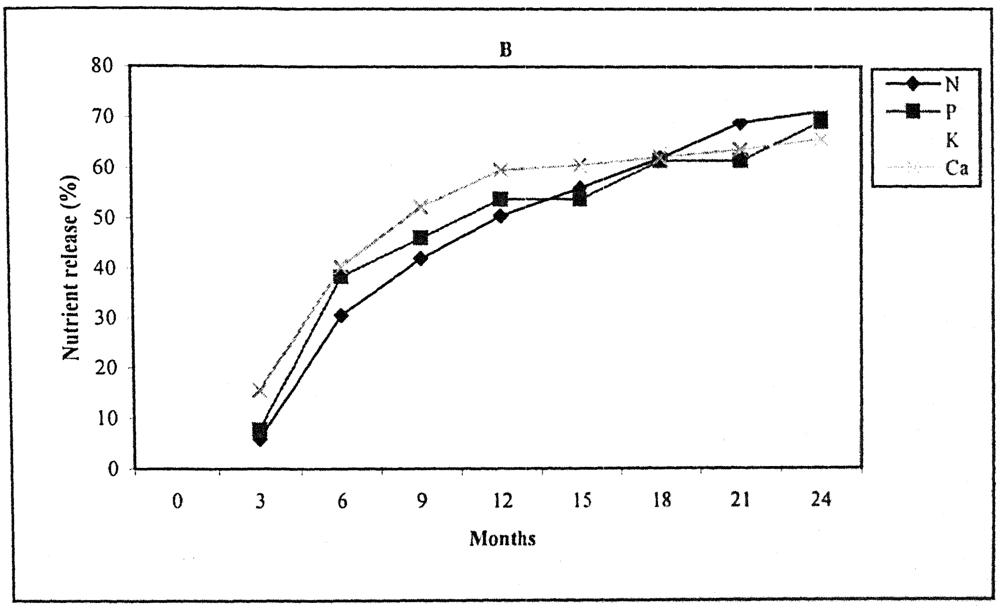


Fig. 15

A. Trend of litter mass remaining in tree leaf litter of *Albizia amara* after decomposition in field condition.

B. Trend of nutrient release (%) by decomposing tree litter of *Albizia amara* in field condition.

The trend of litter decomposition of *Albizia amara* at the present site is quite comparable to similar studies on forest tree litter decomposition in tropical (Paulsamy *et al.*, 1992), temperate (Saxena *et al.*, 1978; Pant and Tewari, 1992) and agroforestry (Malik and Prakash, 1993) situations.

Release of nutrients from decaying organic matter in soil is a critical step in ecosystem function. If the nutrients are released too fast, they can be through soil leaching or volatization. In contrast, if decomposition is too slow, insufficient nutrient are made available with the result that plant growth can be inhibited (Jordan, 1985). The pattern of maximum weight loss and nutrient release during growing season at this site has important implication in uptake of nutrients. Microsite 4 appear to be the most efficient in releasing nutrient through tree leaf litter when compared to the other microsite.

Nutrient Budget

Nutrient budget for nitrogen, phosphorus, potassium and calcium were prepared for three silvopastures microsites of study (Fig. 16). The dotted lines indicate the possible path of recyclable nutrients as a result of root decomposition/decay and litter decomposition.

It is evident from the figure that nutrient lockup in below and aboveground components increased with tree density. This could be attributed to more uptake of nutrients as a result of more extensive root system. The per cent nutrient lockup in above + belowground (of total soil pool) varied from 4.4 to 6.3 per cent in case of nitrogen, 8.1 to 11.0 per cent in case of phosphorus, 0.7 to 1.0 per cent in case of potassium and 0.81 to 1.11 per cent in case of calcium. The per cent nutrient lockup increased with the tree density. The per cent of potential recyclable nutrients through leaf litter (of aboveground nutrients) varied from 7.3 to 9.3 per cent in case nitrogen, 9.1 to 18.7 per cent in case of phosphorus, 9.7 to 10.4 per cent in case of potassium and 12.2 to 15.9 per cent in case of calcium. Additional quantity of recyclable nutrients may also reach the ground floor through

AG (Nutrients in kg/ha)

Nutrients	Microsites		
	MS2	MS3	MS4
N	1177	1318	1623
P	44	48	62
K	431	490	596
Ca	687	757	959

Litter (Nutrients in kg/ha)

Nutrients	Microsites		
	MS2	MS3	MS4
N	86	123	136
P	4	9	10
K	42	51	57
Ca	84	120	134

BG (Nutrients in kg/ha)

Nutrients	Microsites		
	MS2	MS3	MS4
N	176	186	224
P	18	19	22
K	82	86	104
Ca	95	100	119

Soil Pool (Nutrients in kg/ha)

C	1.61×10^5
N	2.91×10^4
P	7.61×10^2
K	6.94×10^4
Ca	9.63×10^4

Fig. 16
Nutrient budgets in respect of nitrogen, phosphorus, potassium, and calcium at the three silvopasture sites of study (1997-1998).

twig/branch/miscellaneous litter. This, however, was not estimated in the present study owing to their lower relative proportion of the total detritus fall or elemental concentration.

Nitrogen cycling through various components is believed to be an important strategy for ecosystem analysis (Pomeroy, 1970). The pattern of nitrogen storage and release observed at this site is in confirmity with the results reported by Cole *et al.* (1968) for Douglas Fir ecosystem, Borman *et al.* (1977) for Northern Hardwood ecosystem, Misra (1979) for natural grassland and Pandeya and Sidha (1989) for arid and semiarid grazing lands.

The phosphorus level in soil are controlled by atmospheric variables on one hand through growth of plant shoots (uptake) and on other hand by mineralization of litter and dead roots by microbial activity. The pattern of phosphorus storage and release at this site is supported by the work of Cole *et al.* (1968) for Douglas Fir ecosystem, Cole *et al.* (1977) for semiarid grassland ecosystem, Dadhich (1979) in some forest trees and Bawa (1992) for Himalayan rangelands.

Increased root activity generally induces more potassium uptake and maximum rate of return of potassium to soil has been recorded through root decomposition (Pandeya and Sidha, 1989). Along with decomposition process it is also contributed by diffusion rate through cell wall in roots (White, 1971; 1973). There are some reports pertaining to potassium cycle on sandy plane of Rajasthan (Singh and Joshi, 1986) and temperate grassland (Kapoor and Singh, 1992). These systems retained very little potassium in aboveground components and released substantially through root and litter decomposition. Similar trend has been observed in this study also. It signifies that such systems may remain stable for some more time in apparent absence of exchangeable potassium.

Low level of calcium lockup in standing vegetation and quite high amount in soil pool indicates lower demands of this nutrient by silvopastures. The pattern

of calcium storage and release at this site is supported by the work of Bawa (1993) while studying nutrient budgets of Himalayan grassland ecosystem.

Soil Fertility

Many workers have reported increased availability of nutrients under tree cover (Sanchez *et al.*, 1985; Sanchez, 1987; Nair, 1989). Also symbiotic nitrogen fixation by trees often result in increased soil nitrogen availability (Alpizar *et al.*, 1986; Montagnini *et al.*, 1986; Dommergues, 1987). In view of this an attempt was made to evaluate the accumulative changes in soil fertility under trees across the microsites during the study period. Table 30 presents the data related to changes in soil fertility status.

It is evident from the table that there was almost no change in organic matter, total nitrogen and total phosphorus content during this period. Maximum increase was registered in case of available nitrogen (16.7 %) followed by available phosphorus (12.5 %), total potassium (11.4 %), total calcium (4.4 %) and available calcium (4.5 %). Generally, higher level of nutrients under trees during two years may be due to litter addition and their decay. Root decay may be another mechanism in this respect (Young, 1991; George and Kumar, 1998). Soil fertility enhancement through litter fall, litter, root decomposition and nutrient cycling in agro-ecosystems involve complex and long term processes that can not be quantified by two year data as presented here. These results do, however provide a basis for comparing litter fall and decomposition processes in silvopastoral systems involving different multipurpose tree species.

Lundgren (1978, 1979) proposed that ameliorating effect of plantation forests on soil occur only during the 5 to 10 year period immediately following canopy closure (the "fallow enrichment phase"). In fact, during maximum production phase actual deterioration in site quality can occur - mineral nutrients are absorbed by trees while litter accumulates on forest floor, but condition are unfavourable for decomposition of organic matter.

Table 30
Changes in soil fertility status under *Albizia amara* based silvopastures (> 24 year) after two years (1997-1998).

Soil fertility	Range	Average
	Initial	
Organic matter (%)	0.97 - 1.38	1.18
Organic carbon (%)	0.57 - 0.79	0.69
Total nitrogen (%)	0.089 - 0.127	0.13
Available nitrogen (%)	0.039 - 0.048	0.040
Total phosphorus (%)	0.003 - 0.007	0.0034
Available phosphorus (%)	0.0004 - 0.0008	0.0007
Total potassium (%)	0.17 - 0.48	0.31
Total calcium (%)	0.26 - 0.59	0.43
Available calcium (%)	0.167 - 0.229	0.21
	After 2 Years	
Organic matter (%)	0.97 - 1.38	1.18
Organic carbon (%)	0.64 - 0.81	0.72
Total nitrogen (%)	0.089 - 0.127	0.13
Available nitrogen (%)	0.049 - 0.051	0.048
Total phosphorus (%)	0.003 - 0.007	0.0034
Available phosphorus (%)	0.0006 - 0.0009	0.0008
Total potassium (%)	0.22 - 0.50	0.35
Total calcium (%)	0.27 - 0.61	0.45
Available calcium (%)	0.170 - 0.231	0.22

In this study where *Albizia amara* trees approached the canopy closure stage, the soil enrichment in almost all the nutrients indicate potential role of this species in ameliorating soil fertility in medium to long term. However, as with all species, rates of nutrient uptake by trees and their recycling through litter varied for each nutrient.

CHAPTER 5

CONCLUSION

CHAPTER V CONCLUSION

The studies on productivity of *Albizia amara* (Roxb.) Boiv. based silvopastoral systems in Bundelkhand region have shown interesting results.

At a microscale, the grown up trees (> 24 years) modified the microclimate under it to a great extent. Lesser availability of solar radiation/ photosynthetically active radiation to the ground vegetation was mainly due to tree density and canopy structure of the systems. Temperature (air and soil) was found to be affected by the availability of solar radiation. Higher temperature regime was recorded in open situation.

Generally, silvopastures maintained higher soil moisture regime at different depths. Also, the soil moisture content generally increased with the increase in tree density. Besides type and density of vegetation cover, type of clay/organic matter at a particular microsite appeared to have influence in determining soil moisture regime. Higher relative humidity under silvopastures was attributed because of lower radiation availability and a more favourable soil moisture regime. Canopy transpiration could also be one of the reasons.

The total density of ground vegetation was higher in open situation when compared to canopy situation. The share of perennial and annual grasses decreased markedly under dense canopy situation. However, share of legumes and weeds increased under canopy. Vigour attributes *viz.*, plant height, tussock diameter, number of tiller/tussock showed a decreasing trend with increase in canopy density in respect of the five perennial grasses *viz.*, *Chrysopogon fulvus*, *Cenchrus ciliaris*, *Heteropogon contortus*, *Sehima nervosum*, *Dicanthium annulatum* at the study site.

Studies on phenology of *Albizia amara* revealed that the tree species has several xerophytic adaptations to protect itself from rigours of dry season. Also, the leaf replacement strategy during summer months appeared to minimize stress by leaf fall and maximize photosynthetic activity during wet warm season of the

year through flushing. Trees attained a plateau in height growth by 25th year. The canopy spread and diameter growth decreased consistently with the increase in tree density.

As expected, highest reduction in aboveground pasture production was found in dense canopy situation followed by medium and light canopy. Similar trend was found in case of belowground biomass. Standing tree biomass increased with the increase in tree density. Similarly, the biomass obtained as a result of lopping also increased with the increase in tree density. The total aboveground productivity and total biomass productivity (aboveground + belowground) under silvopastures increased from 1.75 to 2.20 times and 1.56 to 1.93 times when compared to only pasture land use system. The top feed maintained much higher level of crude protein when compared to the pasture component.

The litter fall in *Albizia amara* was mostly concentrated during January to June, with peaks during May and April. Among litter, the leaves contributed about 70 per cent of total litter fall receipt. The litter production increased with increase in tree density.

The accumulation of all the nutrients *viz.*, nitrogen, phosphorus, potassium and calcium was higher in aboveground parts. Among nutrients, highest accumulation was registered in case of nitrogen followed by calcium, potassium and phosphorus. Thus, heavy thinning of trees at one time may result in removal of soil nutrient pools besides many other deterimental effects on soil.

The ground floor under silvopastures was an important place for accumulation and recycling of nutrients. Return of nutrients through litter fall increased with the increase in tree density. Highest return was registered in case of nitrogen followed by calcium, potassium and phosphorus.

Leaf litter was found to be the most important of various litter parts for nutrient release in silvopastures. Increased rate of leaf litter decomposition was observed with the increase in tree density. As a result of mass loss, the concentration of all the nutrients decreased with time. Maximum decrease was

registered in case of potassium closely followed by nitrogen, phosphorus and calcium. The higher rate of decomposition in rainy season was attributed to suitable temperature and moisture condition for the activity of decomposers and frequent rain source for leaching of water soluble substances.

Nutrient budgets for nitrogen, phosphorus, potassium and calcium were prepared for the three silvopasture microsites. The per cent nutrient lockup in aboveground + belowground (of total soil pool) increased with the tree density. Similarly, per cent of potential recyclable nutrients through leaf litter (of above ground nutrients) increased with the increase in tree density.

An increase in some soil fertility parameters *viz.*, available nitrogen, available phosphorus, total potassium, total calcium and available calcium was registered during the study period. This may be attributed to litter addition and their decay besides root decay. Soil fertility enhancement through litter fall and their decay, root decomposition and nutrient cycling in silvopastures involve complex and long term processes that cannot be quantified by two year data. However, this provide a base for comparing litter fall and decomposition processes in silvopastoral systems involving different multipurpose tree species.

SUMMARY

SUMMARY

In this study (1997-1998) productivity of *Albizia amara* (Roxb.) Boiv. based long rotation silvopastoral systems (> 24 year) maintained at three different densities (about 100, 400 and 600 trees/ha) was compared to open situation (without tree) in an ecosystem context at the Central Research Farm of the Indian Grassland and Fodder Research Institute, Jhansi. Thus four microsites *viz.*, microsite 1 (open situation), microsite 2 (silvopasture having about 100 trees/ha or light canopy), microsite 3 (silvopasture having about 400 trees/ha or medium canopy) and microsite 4 (silvopasture having about 600 trees/ha or dense canopy) were marked for this study.

In open situation, peak photosynthetically active radiation (PAR) availability was recorded in May in both the years. Higher radiation was recorded in 1998 (1987 micro-einstein/m^2/s) when compared to 1997 (1800 micro-einstein/m^2/s). Highest mean PAR availability was recorded in open situation followed by light, medium and dense canopies of *Albizia amara* in both the years. The average reduction in PAR availability was found to be 34.4 per cent, 43.3 per cent and 47.5 per cent under light, medium and dense canopies of *Albizia amara*, respectively.

The air temperature was found to be highest in open situation in May (39.3 ^{o}C) in both the years. In silvopastoral systems, a decreasing trend of air temperature was observed with the increase in tree density. In both the years, the critical difference in air temperature between open and canopy situations was significant. However, the critical difference in between different canopy situations was not significant in both the years. Higher soil temperature regime was recorded in open situation in May in both the years. Peak soil temperature was recorded in 1997 (34.2 ^{o}C) when compared to 1998 (32.3 ^{o}C). The critical difference in soil temperature between open and canopy situations was

significant. The critical differences in between various canopy situations were significant during 1998. In 1997, the differences were significant only between the light and medium canopy situations.

The pattern of soil moisture varied in different months at all the four microsites. More soil moisture was recorded under dense canopy situation in 1997 (16.64 %) when compared to 1998 (13.47 %). The moisture availability was quite high during June to November as compared to the period during December to May. The period June to November received over 87 per cent of total rainfall receipt. In a particular month, generally, more soil moisture was recorded under trees when compared to only pasture situation.

The relative humidity (RH) was found to be highest under the dense canopy situation in August in both the years. Higher RH was recorded under dense canopy situation in 1997 (91 %) when compared to 1998 (90 %). Lowest range of RH was observed in open situation in May in both the years (42 % in 1997 and 39 % in 1998). In silvopastoral systems, an increasing level of RH was observed with the increase in tree density.

The total density of ground vegetation was higher in open situation when compared to the canopy situation. The share of perennial grasses in open situation (80.8 %) decreased markedly under light (72.2 %), dense (66.9 %) and medium (63.5 %) canopy situations. Similarly, the share of annual grasses in open situation (7.6 %) decreased under light (6.9 %), medium (6.3 %) and dense (2.8 %) canopy situations. However, the share of legumes and weeds increased under canopy when compared to the open situation. Vigour attributes *viz.*, plant height, tussock diameter, number of tiller/tussock showed a decreasing trend with increase in canopy density in respect of five perennial grasses *viz.*, *Chrysopogon fulvus, Cenchrus ciliaris, Heteropogon contortus, Sehima nervosum* and *Dicanthium annulatum* at the study site. Average grass height varied from 40.0 to 62.4 cm. More height was recorded in open situation when compared to the canopy situation. The average tussock diameter varied from 17.5 to 21.1 cm. The

average number of tiller varied from 47 to 71. The average length and thickness of root varied from 11.0 cm and 0.24 mm (*Dicanthium annulatum*) to 23.8 cm and 0.51 mm (*Heteropogon contortus*). The highest mean number of root per plant varied from 89/tussock in *Dicanthium annulatum* to 527/tussock in *Cenchrus ciliaris*.

In tree growth characteristics, there was not much difference in average height of trees at different microsites. It appeared that the trees attained a plateau in height growth by this time. The average spread in canopy decreased from light (2.75 m) to dense (2.25 m) canopy situation. Thus, mean annual increment in canopy spread varied from 0.11 to 0.09 m from light to dense canopy situation. The diameter decreased consistently with the increase in tree density. The average growth in diameter (cd/dbh) decreased from light (40.8/28.8 cm) to dense (31.8/22.0 cm) canopy situation. Similarly, mean annual increment in cd/dbh decreased from 1.63/1.15 cm in light canopy situation to 1.27/0.88 cm in dense canopy situation. The length of tap root varied from 1.1 to 1.6 m in different trees of *Albizia amara*. The number of major secondary roots varied from 21 to 29.

The leaf fall was more evident March onwards and continued up to June. This appeared to be a sort of xerophytic adaptation to protect itself from rigours of dry season. Flushing and leaf formation occurred in April-May. However, leaf formation continued up to September. The buds and flowers appeared in April and continued up to May. Pods developed rapidly and reached to full size by June end.

As expected, highest reduction in aboveground pasture production (71.5 %) was under dense tree canopy. The proportion of leguminous forbs/weeds was higher under canopy situations (12.2-14.5 %) when compared to the open situation (10.4 %). Like the aboveground biomass production, significantly higher level of belowground biomass production was recorded in open situation when compared to the canopy situations in both the years. The reduction in belowground pasture production in canopy situations varied from 66.9 per cent to

76.9 per cent. Significantly higher level of total pasture production (aboveground + belowground) was recorded in open situation when compared to the canopy situation in both the years. The reduction in total yield varied from 57.6 per cent to 72.9 per cent in different canopy situations.

Standing tree biomass of *Albizia amara* increased with the increase in tree density. Highest mean total biomass was recorded at microsite 4 (151.6 DM t/ha) followed by microsite 3 (121.2 DM t/ha) and microsite 2 (108.1 DM t/ha). The proportion of aerial biomass to total biomass was highest at microsite 4 (83.4 %) closely followed by microsite 3 (82.8 %) and microsite 2 (82.7 %). The proportion of bole to total aerial production varied from 22.3 per cent to 27.0 per cent. Similarly, ratio in case of branch and pod varied from 55.3 per cent to 61.7 per cent and 1.1 per cent to 1.3 per cent, respectively. The proportion of belowground biomass to aboveground biomass was highest in microsite 3 (17.2 %) followed by microsite 4 (16.6 %) and microsite 2 (10.6 %). Highest total lopped biomass was recorded at microsite 4 (1.85 DM t/ha) followed by microsite 3 (1.56 DM t/ha) and microsite 2 (1.03 DM t/ha). The proportion of mean leaf production was highest at microsite 2 (42.7 %) followed by microsite 4 (41.6 %) and microsite 3 (41.0 %). Higher level of lopped biomass was obtained during 1998 when compared to 1997. This may be attributed to heavier lopping practiced on these stand to open up the canopy during 1997 and higher rainfall receipt during 1998.

Total system productivity (aboveground + belowground) increased with the increase in tree density. Highest total system productivity was recorded at microsite 4 (9.33 DM t/ha/yr) followed by microsite 3 (8.27 DM t/ha/yr), microsite 2 (7.52 DM t/ha/yr) and microsite 1 (4.82 DM t/ha/yr). Thus total system productivity under silvopastures increased from 1.56 to 1.93 times when compared to only pasture land use system. The top feed maintained much higher level of crude protein (16.2 %) when compared to the pasture component (3.9 %).

The litter production of *Albizia amara* varied from 5.00 to 7.95 t/ha/yr with the increase in tree density. Most of the litter fall (around 87 %) was concentrated during January to June, with peaks during March and May. Leaves contributed about 70 per cent of total litter fall receipt during both the years. It was followed by miscellaneous (17 %) and branch litter (13 %).

The aboveground tree and pasture components maintained higher range of all the nutrients *viz.*, N, P, K and Ca when compared to the belowground components. The tree parts maintained higher range of nitrogen concentration when compared to pasture components. The concentration of all the nutrients in leaf litter was lower when compared to standing leaf.

The accumulation of all the nutrients was higher in aboveground parts. The accumulation of nutrients increased from microsite 2 to microsite 4, primarily on account of less pasture yield with the increase in tree density. Highest accumulation of all the nutrients was in branch followed by leaf, root, bole and pod. Among nutrients, highest accumulation was registered in case of nitrogen (1338-1842 kg/ha) followed by calcium (768-1070 kg/ha), potassium (506-695 kg/ha) and phosphorus (63-106 kg/ha).

Return of nutrients through litter fall increased with the increase in tree density. Return of nitrogen through litter fall ranged from 86.0 to 136.1 kg/ha. Similar returns in case of phosphorus, potassium and calcium were in the range of 6.1 to 9.7 kg/ha, 42.3 to 56.6 kg/ha and 84.1 to 134.1 kg/ha, respectively.

Tree leaf litter was found to be the most important for nutrient release in silvopastures. A trend of increased rate of leaf litter decomposition was observed with the increase in tree density. As a result of mass loss, the concentration of all the nutrients decreased with time. Maximum reduction was registered in case of potassium (73 %) closely followed by nitrogen (71 %), phosphorus (69 %) and calcium (66 %). Generally, rapid rate of leaf litter decomposition during rainy season was attributed to suitable temperature and moisture condition for the

activity of decomposers and frequent rain sources for leaching of water soluble substances.

Nutrient budgets for nitrogen, phosphorus, potassium and calcium were prepared for the three silvopasture microsites. The per cent nutrient lock up in above + belowground (of total soil pool) varied from 4.4 to 6.3 per cent in case of nitrogen, 8.1 to 11.0 per cent in case of phosphorus, 0.7 to 1.0 per cent in case of potassium and 0.81 to 1.11 per cent in case of calcium. The per cent nutrient lock up increased with the tree density. Similarly, per cent of potential recyclable nutrients through leaf litter (of aboveground nutrients) varied from 7.3 to 9.3 per cent in case of nitrogen, 9.1 to 18.7 per cent in case of phosphorus, 9.7 to 10.4 per cent in case of potassium and 12.2 to 15.9 per cent in case of calcium.

An increase in some soil fertility parameter *viz.*, available nitrogen (16.7 %), available phosphorus (12.5 %), total potassium (11.4 %), total calcium (4.4 %) and available calcium (4.5 %) was registered during the study period. Generally, higher level of nutrients under trees after two years may be due to litter addition and their decay. Root decay may be another mechanism in this respect. Soil fertility enhancement through litter/root decomposition and nutrients cycling in silvopastures involve complex and long term processes that require long term studies. However, enrichment of soil in almost all the nutrients at the study site where *Albizia amara* trees approached the canopy closure stage, indicated potential role of this tree species in ameliorating soil fertility in the long term.

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* Original not seen